EFFECTS OF AGRICULTURE ON SOIL QUALITY IN NORTHEASTERN GHANA

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ABSTRACT

The effects of agriculture on soil quality were assessed in northeastern Ghana. The farming practices are governed by the farmers' socio-economic conditions and interviews and questionnaires were used to assess these conditions. The effects of the farming practices were evaluated at sixteen sites using soil quality indicators, and soil redistribution was assessed using the ^{137}Cs redistribution.

Food production is dominantly household-based subsistence agriculture. Farmers have small compound farms and nearby bush-fallow farms. Eighty percent of respondents noted worsening soil conditions and soil fertility. Although private ownership of land is commonly suggested to improve soil conservation, 75% percent of respondents were satisfied with the traditional method of land allocation.

The complex relationship between soil and landform, particularly, age of the land surfaces made it difficult to group the sites based solely on farming practices. The soil of upper slope sites had high concretion contents, dithionite-extractable iron contents and magnetic susceptibility values. Four lower slope sites had mottled soils with low concretion contents and oxalate/dithionite iron ratios and magnetic susceptibility values indicative of poorly drained conditions. The final three soils occurred on an active erosional/depositional surface in a small catchment.

The reference inventory of ^{137}Cs was 830 Bq m^{-2} (coefficient of variation of 25%). The highest soil losses (averaging 19 Mg ha^{-1} yr^{-1}) occurred on two upper slope, compound farms. Average soil loss from the bush farms was 7 Mg ha^{-1} yr^{-1}. Negligible soil gain occurred on lower slope sites, indicating net export of eroded soil.

The assessment of soil quality changes focused on the fine soil fraction (<2mm). Soil P, base saturation, and pH were not appreciably affected by cultivation. Upper slope sites had, on average, lost 67% of the pre-cultivation soil organic carbon (SOC). The loss of SOC lead to decreases in total soil N and cation exchange capacity. Less than 50% of the observed SOC loss could be attributed to erosion, indicating the importance of SOC loss through residue removal, burning, and mineralization. Although erosion control would be an important contributor to soil quality maintenance, a broader effort involving many facets of the farming system is required.

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I dedicate this work to my grandmother the late Catherine Aborli Vowotor, and to my father, the late Emerson Yaovi Tay.

Mama, you taught me the value of hard work and honesty very early in life. I wish you were here to see the fruit of your labour.

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1. INTRODUCTION

Degradation of soil quality has been widely recognized as a major effect of agriculture on ecosystems. When native land is opened for agriculture, various changes occur in the physical, chemical and biological properties of the soil. The rate of change in soil properties depends on the inherent characteristics of the soil, climatic conditions and management practices. Management practices are important to soil quality maintenance because they are under the control of the land user. A sustainable land management system is a system that is productive, protective, viable, acceptable, and affords security to the farmer (Dumanski and Smyth, 1993). Thus the evaluation of sustainable land use requires a systems approach that examines the soil as part of an ecosystem with complex internal and external interactions.

The impact of agriculture on soil properties has been extensively evaluated in the humid and semi-arid tropics (Nye and Greenland, 1960; Lal, 1987, 1995). Considerable progress has been made in identifying agronomic systems for sustained agricultural production (Sanchez and Benites, 1987; Lal, 1987, 1995). However, most of these studies were conducted on research stations, which do not represent adequately conditions on farmers' fields. This is especially important in the semi-arid region because of the complex nature of landforms of the region and the particular socio-economic conditions of the farmers. Semi-arid grassland occurs on old land surfaces with highly weathered soils and parent materials. Small-scale farmers who are faced with many constraints that affect their management decisions dominate agriculture. Where as research station results often looked extremely promising, the transferability of their results is limited, causing difficulties in many agricultural development projects (Altieri, 1995). Another important limitation of these studies is the focus on soil fertility constraints rather than productivity. As such, the rate of soil quality degradation and the soil properties that can be used to monitor soil quality degradation were never adequately studied. Also, the relationships between soil quality degradation and the farmers' circumstances were not studied.

The general objective of this research was to evaluate the effects of farming practices on soil quality in a study region located in northeastern Ghana. The specific objectives were to:

i) identify soil properties that can be used as indicators of soil quality,

ii) determine the rate of erosion on different land use types and the impact of erosion on indicators of soil quality,

iii) understand the farmers' socio-economic condition and its effect on their land use decisions.

2. LITERATURE REVIEW

2.1 Conceptual framework

This study examines the influence of farming practices on soil quality using a systems approach. A systems approach to research takes into consideration the complex interaction of the various components of the whole system. As such, it fosters integration of various disciplines (Peterman et al., 1993). It permits synthesis of scientific knowledge in a manner that improves the application of results in the real world and also stimulates basic research in critical areas (Elliott and Cole, 1989).

The systems approach is a useful tool for the evaluation of complex issues such as sustainable land management and soil quality (Karlen et al., 1997; Doran and Parkin, 1994). The soil itself can be viewed as a complex ecological system composed of many interlinked and overlapping subsystems that interact to determine its characteristics, while at the same time interacting with the ecosystem as a whole. The type of soil found in a given location depends on the interaction of five basic factors (parent material, climate, organisms, relief and time) (Jenny, 1961) as well as human beings; farmers and planners using the soil also make decisions within a set of physical and socio-economic constraints.

Decisions and actions taken by humans can affect many natural factors and thus determine whether soil quality will be lowered, sustained, or improved over relatively short times (Karlen et al., 1992). Generally, the perception of physical constraints by farmers is influenced by the prevailing economic situation (Baudry, 1993) especially at the farm level (Golley and Ryszkowski, 1988). Therefore, when examined as part of an ecosystem, soil quality assessments provide an effective method for evaluating direct and indirect effects of human management decisions.

In Ghana, agriculture is dominated by small-scale farmers whose primary objective is household food security. These farmers face severe physical and socio-economic constraints, typical of most developing countries. The socio-economic constraints of the farmers are severe, such that simple sub-discipline research on yield maximization in a monocultural system is not useful for understanding farmer behavior and agronomic choices (Altieri, 1995). The approach used in my study combines natural sciences with socio-economic studies, and could be particularly useful for land management research and sustainable agricultural development in Ghana.

2.1.1 Sustainable land management and soil quality

The issue of sustainability arose from the increased awareness that human population is growing at a rate that the finite natural resources available may not be able to support (Dumanski and Smyth, 1993; Lal and Pierce, 1991; Harwood, 1990). World population is projected to increase from 5.2 billion in 1990 to 8.4 billion by the year 2025 (Lang, 1994). To meet the dietary needs of the increased population, about a 60-70% increase in food production will be required from the soil (Lal and Pierce,1991); however, 88% of the soil resource possess one or more constraints to sustainable production (Oldeman, 1994). Lal and Pierce (1991) cautioned that this could lead to increased human-induced land degradation if sustainable land management strategies are not adopted.

Sustainable land management is defined as the use of land to meet changing human needs, while ensuring long-term socioeconomic and ecological functions of the land for the benefit of present and future generations (Dumanski et al., 1991). The paradigm of sustainable landuse is not yet clearly defined, however, five objectives (productivity, security, protection, viability, and acceptability) have been identified to be used as evaluation tool (Dumanski and Smyth, 1993). Productivity includes the maintenance of crop yields as well as other agricultural and non-agricultural gains through improved land use. Security involves the reduction of the level of production risk by improving the balance between land use, environmental conditions, and changing social conditions. Protection refers to maintenance of the potential of natural resources and prevention of degradation of soil and water quality. Viability is the economic performance of the land use system in relation to economic factors, while acceptability refers to the compatibility of the land use system with the socio-cultural factors of the farming community. A complete evaluation of a land management system requires the integration of these five objectives.

Soil quality or soil health is an important link between farming practices, sustainable land management, and agriculture (Gregorich, 1995). Knowledge about changes in soil quality is required for sustainable management because not only does soil quality express the inherent attributes of a soil, it also expresses the ability of the soil to interact with applied inputs (Larson and Pierce, 1991). Because of the complexity of the soil system, many definitions of soil quality have been suggested (Acton and Gregorich, 1995; Doran and Parkin, 1994; Larson and Pierce, 1994; Acton and Padbury, 1993). Doran and Parkin (1994) reviewed several recently proposed definitions of soil quality. All these definitions had in common the capacity of the soil to function effectively at the present and in the future. In order to adopt a long-term approach to land resource use, the traditional view of soil quality, as measured by soil performance and productivity, is now considered inadequate. Accordingly, the emerging definition of soil quality goes beyond crop production to issues of food safety, human and animal health, and water quality. This expanded definition recognized that soil does not only act as a medium for plant growth, but plays an important role in the overall maintenance of the environment. Doran and Parkin (1994) therefore, suggested that soil quality could be defined as:

> "the capacity of the soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health".

The driving force for a more ecological approach to soil quality definition has come from the sustainable development agenda, in which a central concern with the maintenance of yield is closely associated with a desire to conserve natural resources (Dumanski et al., 1997). Several international conferences on soil and environmental degradation such as the International Workshop on Evaluating Sustainable Land

Management in the Developing World in Chiang Rai, Thailand in 1991; the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil in 1992; the Sustainable Land Management Conference in Lethbridge, Canada in 1993; and the International Congress of Soil Science in Acapulco, Mexico in 1994 are indications of this concern (Doran and Safley, 1997). As well, the new rural development program of the World Bank titled "From Vision to Action" is built around sustainable agricultural development, conservation of natural resources, and sustainable land management (Dumanski et al., 1997).

2.1.2 Soil quality assessment

Soil quality can be assessed qualitatively or quantitatively. Qualitative approaches are often farmer-driven, whereas quantitative approaches are typically science-driven (Romig et al., 1995).

2.1.2.1 Qualitative approaches

A qualitative approach to soil quality evaluation involves the use of descriptive properties such as how the soil looks, feels, and smells as well as its resistance to tillage, the presence of worms, etc. (Acton and Gregorich, 1995; Romig et al., 1995). This approach depends on farmers' field experience and indigenous knowledge. As such it can be subjective. Even though it is subjective, it has much to offer scientists interested in soil quality evaluation (Arshad and Coen, 1992; Pawluk et al., 1992; Harris and Bezdicek, 1994). Harris and Bezdicek (1994) argued that indigenous farmer knowledge based on practical experience could be used to calibrate measured values, allowing a more meaningful description of soil quality. They stated that visible signs and morphological observations in the field can be used by both producers and scientist to recognize degraded soils. Surface sealing, crusting, rills, ponding of water, type of vegetative cover and other such features can be used as indicators of soil degradation and pointed out that this approach can be particularly relevant in regions where resources are limited. Both Arshad and Coen (1992) and Harris and Bezdicek (1994) strongly recommended that qualitative (descriptive) information should be an essential part of quality monitoring programs.

2.1.2.2 Quantitative approaches

Quantitative approaches to soil quality evaluation involve sophisticated analytical procedures aimed at generating data. Several approaches to quantitative assessment of soil quality such as the dynamic assessment approach (Larson and Pierce, 1994), the performance-based approach (Doran and Parkin, 1994), and the multi-scale approach (Karlen et al., 1997) have been proposed. One common feature of all these different approaches is that soil quality is assessed with respect to specific functions of the soil.

The dynamic assessment approach proposed by Larson and Pierce (1994) measures selected soil quality indicators over time using statistical quality control procedures to assess the performance of a given management system rather than comparing it to other systems. The advantage of this approach is that it allows the researcher to focus attention on the attributes that contribute to the behaviour of the system. Doran and Parkin (1994) described a performance-based index, which can be used to evaluate soil function with regards to major issues of (i) sustainable production, (ii) environmental quality, and (iii) human and animal health. Within this framework, six elements were listed: food and fibre production, erosivity, ground water quality, surface water quality, air quality and food quality. This framework has an inherent flexibility, in that weighting factors are assigned to each soil quality element, as determined by geographical considerations, societal concerns and economic constraints.

The multi-scale approach presented by Karlen et al. (1997) identified five scales of soil quality valuation: point, plot , field , farm/watershed, and regional /national /international scales. Point- and plot-scale evaluations are aimed at understanding processes that affect soil quality whereas the higher scales (field - international) of study are used for monitoring soil quality. Consequently, subdisciplinary basic research on soil attributes and indicators of soil quality is carried out at point-scale, while, disciplinary and inter-disciplinary applied research and education that demonstrate how soil quality can change with management are conducted at the plot-scale. The advantage of this approach is that it recognizes that soil quality can be viewed in two distinct ways: (i) as an inherent characteristic of a soil and (ii) as the health or condition of the soil.

2.1.2.3 Indicators of soil quality

Quantitative or qualitative assessment of soil quality requires the use of indicators. The complex nature of soil quality does not allow the use of a single measure (Acton and Gregorich, 1995) and therefore a range of indicators are used. Because of the wide range over which soil properties vary in magnitude, importance, time, and space (Karlen and Scott, 1994; Larson and Pierce, 1991), indicators used to measure soil quality must be clearly defined and selected. Knowledge of pedogenesis, landscape characteristics, and the dynamic processes occurring within a soil are important for selection of appropriate indicators for soil quality evaluation (Karlen et al., 1997). Pedogenesis and landscape characteristics are inherent soil properties, while dynamic processes respond quickly to management practices (Carter et al., 1997).

Soil quality indicators are still being defined. Larson and Pierce (1991) define indicators as measurable soil attributes that are sensitive to the effects of management within a relatively short time. Acton and Padbury (1993) defined them as measurable soil properties that influence the capacity of the soil to produce crops and protect the environment. Doran and Parkin (1994) and Tourco et al. (1994) suggested that apart from being measurable and sensitive, indicators should assess the functioning of the system and indicate temporal and spatial differences at all scales of measurement. Doran and Safley (1997) suggested that, in addition to the above properties, indicators should define the major soil processes and reflect conditions as they exist in the field. They argued that this will increase their usefulness in process-oriented modeling. In general, indicators must integrate soil physical, chemical and biological properties for the evaluation of the effects of climate and management on soil function. They should be relatively easy to use by both scientist and producers, and where possible, they should be attributes that already exist in data banks.

Soil properties such as soil depth, water holding capacity, bulk density, hydraulic conductivity, nutrient availability and retention, organic matter, pH and electrical conductivity have been identified by Arshad and Coen (1992) as desirable indicators. According to them, the listed properties are readily measurable and sensitive to management and, thus, are often affected by degradation processes. Doran and Parkin (1994) and Larson and Pierce (1991, 1994) have listed a suite of soil physical, chemical and biological properties that could be used to assess soil quality world-wide. Physical properties include soil texture, rooting depth, bulk density, infiltration, water holding capacity, and structure. Chemical properties include organic carbon, organic and mineral N, mineral P and K, pH, and electrical conductivity. Biological properties include microbial biomass, C and N mineralization, and soil respiration.

These physical, chemical and biological properties could be considered the minimum data set that can be used to assess changes in soil quality (Larson and Pierce, 1991, 1994). They suggested that standardized methodologies and procedures for assessing changes in soil quality should be established and that reference levels are needed to determine whether a soil is being degraded, maintained or improved. The reference could either be an earlier data set from the same soil, modal data for the soil, or comparison to data from the same soil in native conditions. Knowledge of whether changes in the minimum data set of soil properties represent conservation, enhancement or degradation is more critical to soil quality (Larson and Pierce, 1991) assessment than quantitative estimates of soil quality.

Larson and Pierce (1994) also suggested that soil properties that are too costly or difficult to measure but would be desirable parameters for soil quality assessment could be predicted from other soil properties using pedotransfer functions (Bouma, 1989). The pedotransfer function is a mathematical function that relates a given soil property with other, more simply measured, properties for use in evaluations of soil quality (Larson and Pierce, 1991). Phosphate-sorption capacity, cation exchange capacity, bulk density, water retention, porosity, hydraulic conductivity, electrical conductivity, saturated conductivity, soil productivity, and rooting depth are some of soil properties for which pedotransfer functions have been proposed for. A similar proposal was made by Doran and Parkin (1994) who added cation exchange capacity, and aggregate stability to the pedotransfer indicators listed above. Cation exchange capacity, for example can be estimated from soil organic matter, pH and clay content.

Doran and Parkin (1994) emphasized that the listed properties are only basic for initial characterization of soil quality and that other sets of properties may be needed as dictated by existing data bank, climatic, geographic, and socio-economic conditions or as indicated by assessment of the basic indicators.

2.2 Climate and soils of the semi-arid Tropics

The literature on soil quality emphasizes the need to choose soil quality indicators appropriate to the physical and socio-economic environment of the study area. The purpose of the next section is to review the literature on the environment of the study region to develop a framework for the selection of soil quality indicators.

2.2.1 Climate

As the name implies, the semi-arid tropics are characterized by long dry periods and short rainy seasons. The climate of the West African semi-arid zone is influenced by two dominant air masses. The north-easterly dry Harmattan, which comes from the Sahara, and the south-westerly monsoon of humid oceanic air (Kowal and Kassam, 1978; Jones and Wild, 1975). In northern Ghana, the dominant wind for most of the year is the north-east Harmattan and in the south, the south-west monsoons. The influence of these winds is seen in a short and unimodal wet season in the north, and a longer and bimodal rainy season in the south (Jones and Wild, 1975).

These differences in rainfall pattern have resulted in three broad ecological zones. The Sahelian zone in the north (including northeastern Ghana) has less than 600 mm of annual rainfall and a rainy season of two to four months, the North Sudanian zone has 600 to 1000 mm and four to five months of rain and, and the South Sudanian zone has more than 1000 mm of rainfall and five to six months of rain (Adu, 1969).

The prevailing climatic conditions of distinct wet and dry seasons has a direct effect on soil forming processes and agriculture in the region. The high temperatures during the dry season encourage accelerated chemical decomposition and deep weathering of rocks, and the sudden torrential rainfall following a prolonged dry season (during which the grass cover is often burnt) induces topsoil erosion. Most of the rains occur in high intensity storms resulting in runoff and severe erosion, even on relatively flat lands (Kowal and Kassam, 1978). The loss of topsoil can also lead to irreversible hardening (laterization) of the exposed subsoil (Eswaran et al., 1992). Although total rainfall in a year can be adequate, major problems for agriculture are posed by its variability, distribution and irregularities. Climatic constraints include rainfall seasonality, with nearly 90% of annual precipitation falling in the rainy season, wide fluctuations between and within rainy seasons, and highly uncertain dates of arrival and cessation of seasonal rainfall. This high spatial and temporal variability and high potential evapotranspiration influence the proportions of rainfall available for crop growth.

2.2.2 Soils

A wide variety of soils occur in semi-arid tropics due to the complexity of the land forms in the region (Vlek, 1993; Eswaran et al., 1992; Stewart et al., 1991). Alfisols, Oxisols, Ultisols, and Entisols predominate while Vertisols, Inceptisols and Alluvisols occur in small patches on lower slopes, river plains and valleys (El-Swaify and Caldwell, 1991; Lal, 1987). Among the soil orders, Alfisols, Oxisols, Ultisols and Inceptisols are common in the region under study, and at the study site itself Alfisols are dominant (Adu, 1969).

Alfisols are relatively fertile compared with Oxisols and Ultisols, but they have poorer soil physical properties (Lal, 1987), which limit their productivity potential. The soils are characterized by a coarse-textured surface horizon overlying a clayey subsurface layer that may compound problems of hardpan common in these soils (Bablola and Lal, 1977). About 250 million hectares of Alfisols in semi-arid West Africa have hardened laterite at a shallow depth, about 5 to 25 cm below the surface (Lal, 1987). As a result, exploitable rooting depth is limited and becomes an important constraint affecting productivity. Also, these poor structural characteristics have resulted in high potential for erosion, vulnerability to sealing and crusting and generally low fertility (Hauffe, 1989; Quansah et al., 1989). The presence of these hardpans also imparts a complex mineralogical characteristic to the soils that does not reflect present climatic and management conditions (Eswaran et al., 1992). To fully appreciate these soils and the soil constraints that face agriculture in the region it is important to understand the genesis of these hardpans and, therefore, the geomorphology of the region (Ahn, 1974).

2.2.2.1 Soil-geomorphic relationships in the semi-arid Tropics

Most of the semi-arid tropical lands are made up of ancient rocks known as the basement complex (Ahn, 1974), which have undergone a long history of erosion. These rocks belong to the oldest geological period, the Pre-Cambrian age. Because of the absence of Pleistocene glaciation, many of the landscapes pre-date the Quaternary. Remnants of peneplains as old as mid-Tertiary (about 20 million years) are common (Eswaran et al., 1992). Also common are lithological discontinuities such as stone-lines, quartz gravels and ferruginous nodules (Ahn, 1974).

Even though the tropics did not undergo glaciation during the Pleistocene, other equally dramatic climate events occurred during this period that reshaped the entire tropical landscape. A prolonged period of cooling and aridity, which resulted in drastic vegetation changes (Thomas, 1994).. Most of the forested areas were converted to savannas and the savannas to deserts. This prolonged dry period was followed by a period of much wetter climate in the early Holocene that resulted in huge floods with high sediment loads and the carving of bedrock channels. As well, uplift, tilting and erosion are some of the important tectonic processes that control the dynamics of the landscapes in tropical regions. These processes accelerated surface erosion and relief inversion (Thomas, 1994).

Three broad categories of landforms and soil toposequences (catenas) have been identified in the semiarid savanna as follows: catenas without rock outcrops, catenas with rock outcrop, and plinthite catenas (Gerrard, 1981). Catenas without rock are the youngest geomorphic surfaces and occur as narrow flood plains along some of the major streams. Catenas with rock outcrops occur in small scattered patches on old surfaces on the highest parts of the landscape with slope angles between 8° and 10°. Catenas with plinthite also occur on the oldest erosion surfaces and on the highest part of the landscape but the slope form is fairly constant with a flattened upper slope and summit separated from a straight or concave middle portion (Ahn, 1974). These plinthite catenas are the classic African catenas with smooth concave-convex slopes (Ahn, 1974) and are the dominant landscapes in semi-arid West Africa (Bui et al., 1990).

2.2.2.2 Plinthite landscapes of the west African semi-arid region

Plinthite is an iron-rich, humus-poor mixture of clay with quartz and other materials that commonly occurs as dark red horizons (Soil Survey Staff, 1994). It is firm to very firm when moist and hard or very hard when dry, changing to an irreversible ironstone hardpan or irregular aggregates on exposure to repeated wetting and drying, especially if it is also exposed to the heat of the sun. The irreversibly hardened form is known as petroplinthite (Soil Survey Staff, 1994; Eswaran et al., 1990). Petroplinthite frequently occurs in the soil as loose or slightly cemented gravel, and is often referred to as ironstone, lateritic gravel or concretions (Eswaran et al., 1990).

Petroplinthite gravel or concretions are very common in soils of older landsurfaces, such as West Africa, where they occur as layers varying in thickness from a few centimeters to about 1 m (Eswaran et al., 1990). These petroplinthite gravels may have no pedogenic relationship to the soil in which they occur, and their behavior and roles are similar to stones of quartz or granite in other alluvial or colluvial soils. If an aquic soil moisture regime prevails, re-cementation of the petroplinthite may commence again leading to the formation of a petroferric contact (Eswaran et al., 1990). A petroferric contact is a boundary between the soil and a continuous layer of indurated iron rich material (Soil Survey Staff, 1994).

The occurrence of plinthite profiles on upper slope positions is interesting because ferruginous materials are formed in valleys and lower slopes. According to Ollier (1991) the iron was brought into the valleys by lateral groundwater movement, and concentrated into a ferruginous crust. Erosion of surrounding slopes with subsequent relief inversion raised (in a relative sense) the low lying ferruginous crust to their current high elevation.

2.2.2.3 Formation of ferruginous concretions

Ferruginous nodules or concretions are formed as a result of weathering associated with development of these old soils, and are found most commonly in soils formed in regions that have alternating wet and dry periods. These climatic conditions favor the alternating reduction-oxidation and hydration essential for development of concretions or nodules (Sherman and Kanehiro, 1954). The release of Fe from primary minerals is necessary for the formation of nodules and concretions, but the most important process is the local accumulation of Fe oxides.

The release of Fe from primary minerals usually require the dissolution, transport and re-precipitation of the Fe-oxides. The process of Fe segregation involves four basic steps: 1) mobilization of Fe as Fe^{2+}, 2) transportation of Fe^{2+} by diffusion or mass flow due to gravity or capillarity, 3) immobilization of Fe^{2+} by precipitation of solid Fe^{2+} oxides and adsorption on clays, and 4) oxidation of Fe^{2+} by O_2 or other oxidants to Fe^{3+}oxides (Esawaran et al., 1990; van Breeman, 1988). This process results in relatively large amounts of fine-grained, poorly crystalline or amorphous Fe oxides that become crystalline upon drying and dehydration at the high temperatures prevalent in the semi-arid tropics (Sherman et al., 1964).

The iron oxide is deposited in the soil as limonite, geothite, and probably lepidocrite in certain cases (Sherman and Kanehiro, 1954). When the subsoil is exposed by cultivation or by the loss of natural vegetation cover, the hydrated Fe oxides are dehydrated to form hematite. Some of the crystallized Fe oxides become concentrated to form ferruginous concretions or nodules such as those frequently encountered in the northern region of Ghana. The stable and frequent Fe(III) oxides found in these soils are goethite and hematite (Nartey, 1994). The size of the Fe concretions increases with time of exposure to the surface (Sherman and Kanehiro, 1954). Nodules with diffuse fabric are formed if there is a continuous supply of iron; where there is periodicity in the supply of iron, concretions with concentric fabric result (Eswaran et al., 1990). The concentration of Fe oxide in the soils may range from <0.1% to >50% (Schwertmann and Taylor, 1989).

2.3 Traditional farming systems in the semi-arid Tropics

Within the semi-arid regions of the tropics, especially those of West and Central Africa, shifting cultivation and settled subsistence are the common systems of cultivation practiced (Ahn, 1974; Sanchez, 1976). The nature of agriculture is essentially subsistence with low input and manual cultivation with tools that limit the amount of land which can be cleared in any one year (Ahn, 1974; Lal, 1987). Farmers aim at producing a range of crops mainly for their own consumption, as opposed to concentrating on one or two crops for sale in order to buy their own needs. Small or moderate-sized areas, sometimes scattered in several patches, are cultivated. In the study area, subsistence farming is practised around the household compound while shifting cultivation is practised in woodlands about two to ten km away from the households. Locally, these systems are known as compound farming and bush farming systems, respectively, and these terms will be used in this document.

In compound farming, the farmers create a pattern of fertile, permanently cropped fields around the compounds houses that receive regular application of organic manure and household waste. Consequently, fertility gradually declines with increasing distances from the house. On the other hand, shifting cultivation involves a deliberate alteration between annual crop production and periods of vegetative fallow. Ideally the land is cultivated for about 1 to 3 years and then left to regrowth for about 10 years or more (Sanchez, 1976). Thus, after a few years of cultivation, the land is left to fallow and a new field is cleared for cultivation. Land clearing is done by the slash and burn method and soil fertility maintenance is dependent on nutrient cycling and biological processes such as nitrogen fixation and nutrient accumulation in biomass during the fallow period. Fertilizer use is very limited. Because the system relies mainly on fallow regrowth of trees and other vegetation for fertility regeneration (Nye and Greenland, 1960, 1964) its viability depends on how well alternating periods of cropping and fallowing maintain a balance between nutrient loss (during cropping) and nutrient gain (during fallow) (Chinene and Dynoodt, 1994).

2.4 Controls on the magnitude and direction of changes in soil quality

The selection of specific indicators for soil quality changes in a region must also reflect the mechanisms by which the soil quality changes occur. The literature on soil quality typically separates the controls on soil quality changes into those that occur *in situ* (e.g. mineralization of organic matter) and those that involve the export of soil from the study site (typically by erosion processes). An important initial stage in a soil quality evaluation is to determine the importance of the two types of controls on soil quality changes.

In the study region, the *in situ* changes in soil quality are driven by the nature of the agricultural practices. As discussed above, the farming system can be divided into compound farming and bush farming. Compound farming involves the use of animal wastes and plant residues as nutrient sources whereas the bush farming systems are dependent on nutrient replacement through a fallow period.

The second major control on soil quality changes is by redistribution of soil within (and beyond) the study region by erosion processes. Generally, the *in situ* changes in quality affect the more dynamic soil properties (organic matter, plant available nutrients) but have a limited effect on the morphology of the soil itself. Soil redistribution, on the other hand, can greatly affect the morphology of the soil itself by either removal of the surface soil (during soil loss) or burial of the soil surface (during soil deposition). A major task of an initial soil quality evaluation is to determine the relative balance between soil loss and soil deposition in the study region.

Although the effects of soil deposition can be of short-term importance, crop burial, for example, the effects of soil loss tend to be of greater long-term relevance. The effects of soil loss can be broken into two broad categories (Larson and Pierce, 1994). The first is the loss of organically enriched surface soil (topsoil). The second group of effects occurs due to the incorporation of subsoil layers into the surface soil by tillage following the removal of the surface soil. These subsoil layers may have growth-limiting characteristics that will further limit the productivity of the soil beyond that attributable solely to nutrient loss.

Soil erosion by water is the most important type of erosion in Ghana. According to the Soil Research Institute (1971), about 29.9% of the country is subject to slight to moderate sheet erosion, 43.3 % to severe sheet and gully erosion, and 23 % to very severe sheet and gully erosion on hilly and steep slopes. The northeastern region is the most highly susceptible to erosion because of the relatively thin layer of solum and the variable dry and wet climatic condition of the region.

The process of water erosion falls into two major sequential events: (1) detachment of individual particles from the soil mass and (2) their transport by raindrops and running water. Deposition occurs when sufficient energy is no longer available to transport the particles. The detached material is usually the fine soil, where plant nutrients are most concentrated. The consequent exposure of subsoil often leads to a lower rate of water entry, increased runoff and further soil loss. Erodibility defines the resistance of a soil type to both detachment and transport. It involves those soil properties that affect infiltration rate and permeability, as well as properties that determine the effects of dispersion, splashing, abrasion and transporting forces of rainfall and runoff (Morgan, 1986).

2.4.1 In- situ changes to soil quality: nutrient dynamics during cultivation and fallow cycles

Ideally, slash and burn agriculture is ecologically stable under very low population density (Nye and Greenland, 1960). Under this condition, the size of the cropped land could be small enough that it is surrounded by native vegetation; the length of cultivation is kept below two years; and the length of fallow is kept sufficiently long (Juo and Manu, 1996). As the cropped fields become larger and the length of fallow becomes shorter the nutrient cycling equilibrium is broken. A significant portion of nutrients released from burning may be lost through erosion, runoff or through leaching and crop removal. The total nutrient stock in the whole ecosystem gradually declines during subsequent cycles of fallow and cropping. Dynamics of the total nutrient stock depend on maintenance of soil organic carbon.

When the native land is first cultivated, there is a large, rapid decrease in soil organic matter (van Veen and Paul, 1981; Lynch, 1984; Richter et al., 1990), mainly within the first ten years of cultivation. This can have a positive effect on soil fertility through the gradual releases of nutrients from the original vegetation (Chinene and Dynoodt, 1994). The rate of organic matter decomposition and nutrient release is controlled by physical, chemical, biological and management factors (Wood et al., 1990; Ismail et al., 1994). Management controls include cultural practices such as tillage, residue management, cropping intensity and fertilization. Burning for example, mobilizes large amounts of cations (Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}) and anions (Cl^{-}, SO_4^{2+}) as water-soluble elements present in ashes, and from soil chemical reactions resulting from heating (Khanna and Raison, 1986). Frequently the amount of nutrient elements in the ash is in the order of Ca>K>Mg>P.

Following this initial flush of decomposition, organic matter declines slowly until the soil reaches a new equilibrium for the types of cultivation system being used (Tiessen et al., 1982). Most often, the new equilibrium levels are below those of the native land because substantial losses of C, N, and S to the atmosphere through volatilization

(Sanchez, 1976). Rapid increases in soil pH, exchangeable bases, effective CEC and available P in surface soils are also common (Nye and Greenland, 1960; Andriesse and Koopmans, 1984; Andriesse and Schelaas, 1987a, b). The time required to reach a new equilibrium after cultivation has been estimated at 30 to 50 years (Mann, 1986), 60 to 70 years (Martel and Paul, 1974) or longer, especially for intensively weathered soils (Nye and Greenland, 1960; Paul and van Veen, 1978; Tiessen et al., 1982; Chinene and Dynoodt, 1994)

The natural vegetation growing on intensively weathered soils is less abundant and recycles smaller amounts of nutrients because it depends on nutrient released from decomposing plant biomass to meet mineral requirements (Juo and Manu, 1996). In these soils, especially low-base status soils of the tropics, over 80% of the essential nutrients are held by the plant biomass with very little held in the bulk soil (Sanchez, 1976). This unbalanced nutrient distribution between biomass and the soil is reflected in the substantial loss of mineral nutrients released during the slash and burn operation if the soil system is unable to retain them (Juo and Manu, 1996). If these natural systems are transformed to human-managed systems, the nutrient pool, primarily the organic components, becomes drastically reduced. Thus, the overall effect of shifting cultivation is not only that of organic matter depletion, but the reaching of new equilibrium levels that are below those of the native vegetation. Studies show that for a crop: fallow ratio of 2:12 years, organic carbon equilibrium is about 75 % of the original level. According to Nye and Greenland (1960), when the crop: fallow ratio becomes narrower due to population pressures, the new equilibrium is attained at about 50% of the native vegetation.

Soil organic carbon is generally considered the most universal indicator of soil quality, particularly in agroecosystems because it affects so many other chemical, physical and biological properties of the soil (Boyle et al., 1989, Granatstein and Bezdicek, 1992; Larson and Pierce, 1991; Doran and Parkin, 1994; Ismail et al., 1994). Soil organic matter affects plant nutrient levels, soil structure, water stable aggregates, tilth, and water holding capacity (Haynes and Swift, 1990; Larson and Pierce, 1991;

Swift, 1997). It is the dominant source of nutrients, especially in low input agricultural systems such as those found in the semi-arid tropics (Lal, 1985). In these systems, the loss of organic materials from the soil surface is especially devastating, because the soils are inherently low in fertility and most of the essential nutrients are concentrated in the top few centimeters of soil.

The loss of soil organic matter and nutrients results in an overall soil fertility loss (Verity and Anderson, 1990; Geng and Coote, 1991). As substrates for microbial consumption become depleted and nutrient deficiencies limit plant growth and residue inputs, further losses of macro-aggregate structure occur reducing plant growth, hence increasing erosion (Tiessen and Stewart, 1983; Parton et al., 1988). Eventually, the labile organic matter pools may be so depleted that the rate of C mineralization in disturbed soils becomes very low. Unless replenished, nutrient depletion by crop removal, leaching, runoff and erosion, and volatilization result in the loss of soil fertility. Loss of bases and increases in acidity by leaching are direct results of a decline in soil colloids. The leaching losses of nutrients to subsoil are increased when deep-rooted perennials that would otherwise effectively recycle these nutrients are absent (Lal, 1987).

The mechanism of soil enrichment under fallow vegetation is associated with accumulation of litter produced during the fallow period. Fallow vegetation derives its mineral nutrients mainly from the soil and hence the fertility status of the soil at the time of fallow is very important. Nutrient uptake by the fallow vegetation may lead to a decline in soil pH and subsequent decline in fertility in soils containing limited reserves of exchangeable bases and major nutrients (Juo and Manu, 1996; Greenland, 1975, Ahn, 1959).

The age of the fallow vegetation is another important determinant of nutrient accumulation under fallow vegetation. Old, matured fallow vegetation stores larger amounts of nutrients than younger ones. Leaves and branches are important nutrient sinks on young trees; in older trees, large quantities of nutrients are stored in the trunks. With age, the quantity and quality of fallow species increase, increasing the ability of the fallow to restore fertility of the soil (Szott et al., 1991). Grasses that colonize the land in the early stage of fallow are often efficient K accumulators while perennial shrubs and tree legume are good P and Ca accumulators during later stages of succession. Herbaceous legumes fix nitrogen. Studies show that the total biomass accumulation during the first 10 years of fallow varies considerably, ranging from 48 to 160 t ha^{-1} (Szott et al., 1991) and reaching a steady state after 7 to 15 years of fallow. The total amount of biomass at this steady state is typically only 35 to 75% of the original biomass (Szott et al., 1991; Jaiyeoba, 1997). This suggests that the total amount of biomass of the secondary forest may take hundreds of years to reach levels comparable with that of the primary level once the total nutrient stock has been significantly reduced and the nutrient cycling mechanisms are disrupted by repeated cycles of slash and burn cultivation.

The effects of the *in situ* changes on the dynamic soil properties must be separated from changes due to soil loss. Pennock (1997) argued that it is very important to distinguish between selective erosion and bulk erosion because of the possibility of "fertility erosion" associated with selective erosion. Selectively removed materials are lost in amounts disproportionate to their relative amounts in the bulk soil material. Most often materials removed are soil organic matter and fine soil particles (clay and silt). Because the soil nutrients and exchange sites are concentrated in the soil organic matter and clay fractions, this selective loss of material has greater impact on fertility than the bulk soil loss itself would suggest. It is, therefore, apparent that smaller erosion losses, which may seem unimportant with respect to volume of soil removed, may be very important as far as the nutritional depletion and the general decline in the productive capacity of the surface soil is concerned.

2.4.2 Growth-limiting characteristics of plinthite

The incorporation of growth-limiting subsoil layers into the surface soil layer is a second major consequence of soil loss. In some tropical and sub-tropical regions this concern is especially acute due to the presence of plinthite layers in the subsoil.

Plinthite, and its related forms such as petroplinthite and the petroferric contact, reduces soil quality because it presents physical and chemical constraints that hinder farming operations and reduce productivity. In general, plinthite forms a textural unconformity (Sanchez, 1976). It is a semi-permeable subsoil feature (Eswaran et al., 1990) of high bulk density and extreme strength. This leads to reduction in the volume of macropores and total porosity of the soil (Cassel and Lal, 1992). The textural unconformity of the subsoil plinthite layer causes water to collect above it, limiting the potential uses of the soil to crops requiring water saturation, such as rice. According to Daniels et al. (1978) about 10% platy plinthite is required to perch water.

The textural unconformity also increases the erosion hazard by affecting infiltration rate of the soil. As the topsoil is eroded, the subsoil plinthite is exposed and becomes hardened and cemented to form irreversibly hard ironstone pans and gravels of petroplinthite (Eswaran et al., 1990). Petroplinthite concretions behave like quartz gravels and stones in soils by reducing the effective soil volume for water and plant nutrient movement, plant uptake and root growth (Eswaran et al., 1990). When plinthite and petroplinthite occur close to the soil surface they increase mechanical impedance to shoot emergence and root growth (Cassel and Lal, 1992). The hardened petroplinthite formation is an irreversible stage of degradation, which results in land abandonment.

In addition to physical constraints, plinthite presents chemical constraints associated with its mineralogy. The mineralogy of plinthite is dominated by oxides, hydroxides and oxyhydroxides of Fe and Al. Iron oxides are small, with crystal size of 10 to 50 nm (Schwertmann and Herbillion, 1992); therefore, they possess a large specific surface area that effectively contribute to the overall surface area of soils. In oxide systems, the charge is entirely pH dependent. The chemical nature and specific surface area of Fe oxides make them efficient sorbents and therefore sinks for 1) inorganic anions such as silicates, phosphates and molybdate, 2) organic anions and molecules such as citrate, fulvic and humic materials, and 3) cations such as Al, Cu, Pb, V, Zn, Co, Cr and Ni, some of which are essential for plant growth (Schwertmann and Taylor, 1989). The best known effect of the Fe-oxide surface is its high affinity for phosphorus retention

(Schwertmann and Herbillion, 1992) as demonstrated by drastic decrease in P adsorption after differential removal of the Fe oxides by citrate-bicarbonate-dithionite (CBD). P availability in soils is often a limiting factor for plant growth even though the total amount of soil-P may be high. Ferruginous gravels or nodules sorb P and are capable of raising the sorption level of soils (Tiessen et al., 1991b and 1993) despite their apparent inert nature, because of their reactive Fe and Al oxide content.

2.4.3. Effects of rock fragment/concretions on soil erosion by water

There is a strong interaction between the presence of the plinthite and concretions in the surface soil and the rate of soil erosion by water. The effect of rock fragments on infiltration rates and percolation rates are discussed by Brakensiek and Rawls (1994) and Valentin (1994). Infiltration determines the rates and amounts of surface water that are available to overland flow and watershed runoff. The effect of rock fragments on infiltration is very controversial - some reports suggest negative relationship and others a positive relationship. These apparent contradictions could be related to the position (i.e., embedded in the soil or resting on the soil surface), size, and cover of rock fragments as well as structure of the fine earth (Poesen et al, 1994; Valentin, 1994). Rock fragments embedded in the soil reduce infiltration and increase overland flow whereas those resting on the surface may increase or decrease inflitration (Valentin, 1994). Larger rock fragments increase infiltration and smaller rock fragments decrease it (Brakensiek and Rawls; 1994, Valentin, 1994). The relationship between rock fragments and sealing depends on climatic conditions (Valentin, 1994). In dry areas of West Africa, Valentin (1994) found that rock fragments are embedded in a vesicular seal and therefore generate heavy runoff. Conversely in wetter areas, finer gravels are mainly free at the soil surface and favour infiltration.

At the mesoplot scale (i.e., 1cm^2 to 10^2 m^2), the processes of overland flow generation near the edge of the rock fragment and the continuity of overland flow along a hill slopeare controlled by the rock fragment cover (Poesen and Lavee, 1994). At this scale, rock fragments have ambivalent effects depending on the type of fine earth porosity, soil surface slope, vertical position and size of rock fragments and by the occurrence of horseshoe vortex erosion. As a consequence, the relationship between rock fragment cover and sediment yield is variable depending on which of these factors is most prominent (Poesen et al., 1994). If a very large proportion of the surface is covered with embedded rock fragments, the protective effect of the rock fragments overrule the effects of flow concentration (Poesen et al., 1994). As such it is important to distinguish between rock fragments at the surface and those below the surface when discussing their effects on hydrological processes (Poesen and Lavee, 1994).

Soil erosion at the macro-scale is a combination of processes taking place at the micro- and meso-scales as well as subprocesses that occur in rills and gullies (Poesen et al., 1994). In general, rock fragments at the soil surface have a negative effect on sediment yield and can be considered soil surface stabilizers. Sediment yield at the macro-scale is the result of the combined subprocesses taking place at the micro- and meso-scale. Thus, in the study area, whether the effects of concretions on soil erosion is at the surface or below surface is time dependent. When the land is first opened for cultivation, concretions below the surface will reduce infiltration, thereby increasing runoff and erosion. With time, the concretions become exposed and loose on the surface, shielding the soil surface from detachment by raindrop splash and runoff.

2.5 Soil redistribution studies

2.5.1 The ^{137}Cs *technique*

The ^{137}Cs tracer technique is an important development in soil erosion studies because it attempts to overcome the limitation of previous soil erosion research methods. Martz and de Jong (1987) listed some of the advantages of the ^{137}Cs technique as follows:

(1) The ^{137}Cs technique provides information on soil redistribution that is linearly time-integrated, incorporating fluctuations in erosion intensity due to variations in rainfall, wind and land management practices. The direct

measurement studies are generally short-term (intensive) and thus do not allow for retrospective assessment of erosion rates.

(2) Installation of equipment at the site of study is not required for the ^{137}Cs technique and measurements can be taken from a large number of sites in a relatively short time.

(3) It evaluates both soil loss and soil gain and, thus, gives estimates of net erosion. The net erosion estimates are process-integrated, reflecting the combined impact of all soil redistribution agents acting in the landscape.

^{137}Cesium is an artificial radionuclide with a half life of about 30.2 years, produced as a result of nuclear fission. Its presence in the soil is due to thermonuclear weapon testing during the 1950's and early 1960's (Ritchie and McHenry, 1990; Walling and Quine, 1990 and 1995). World-wide deposition of the isotope occurred following its dispersion and movement by the global atmospheric circulation system. The concentration of these isotopes in precipitation depends on the specific meteorological conditions and the quantity of radioactive material present in the atmosphere (Walling and Quine, 1995). Even though the relationship of ^{137}Cs to rainfall varies in both time and space, the overall annual pattern of fallout is similar throughout the world (Longmore (McCallan) et al.,1983).

The value of ^{137}Cs as a sediment tracer lies in its rapid and strong adsorption by soil particles, particularly the clay fraction (Rogowski and Tamura, 1970). Its subsequent redistribution is a direct consequences of erosion, transport and deposition of soil particles occurring during the period extending from the main phase of atmospheric deposition to the time of sampling (Walling and Quine, 1995). Cultivation distributes the cesium throughout the plough layer. Where, however, soils are essentially undisturbed, as in the case of permanent pasture and rangeland, cesium is preferentially concentrated near the surface with distribution showing an exponential decrease with soil depth (Ritchie and McHenry, 1990).

Assessment of ^{137}Cs redistribution is based on the comparison of the measured inventories (total activity per unit area) at individual sampling points to an equivalent estimate of the inventory representing the cumulative atmospheric fallout at the site. The ^{137}Cs concentration in cultivated soils can be compared with that of stable uneroded soils (de Jong et al., 1982, Longmore (McCallan) et al., 1983) to estimate soil erosion. This method uses adjacent, undisturbed, non-eroded locations as control sites where the cumulative input or reference inventory of ^{137}Cs is established. Where sample inventories are lower than the local reference inventory, losses of cesium-labeled soil and therefore erosion is inferred. Similarly, sample inventories in excess of the reference levels are indicative of the deposition of cesium-labeled soil (Walling and Quine, 1995). Qualitative assessment of sediment redistribution is thus derived from the magnitude and direction of the measured deviation from the local reference level.

2.5.2. Application of ^{137}Cs technique in soil erosion research

The estimation of soil erosion using ^{137}Cs derived from radioactive fallout has been extensively applied in North America and Europe since its development in the early 70s (Ritchie and McHenry, 1990). In Canada, for example it has been successfully applied in a variety of studies. A study by de Jong et al. (1982) demonstrated the effectiveness of ^{137}Cs measurements in estimating the amounts of soil redistribution in cultivated landscapes in Saskatchewan. ^{137}Cs concentrations in native grassland showed little variation within various landform segments, whereas the redistribution of soil and ^{137}Cs activity were pronounced in various landscape segments on cultivated sites. Subsequent studies in Saskatchewan (Pennock and de Jong, 1987; Martz and de Jong, 1987; Sutherland et al., 1991) have explored the relationship between landscape elements to extrapolate from point measurements of soil losses or gains. In a number of soil quality studies (de Jong and Kachanoski, 1984, Pennock et al. 1994a and 1994b), the ^{137}Cs technique has been the most powerful tool employed.

The use of the cesuim method outside the North America and Europe has been limited due to uncertainties about the existence of measurable amounts Cs-137 in these areas (Walling and Quine, 1995). Total fallout is greater in the northern hemisphere than in the southern hemisphere ((UNSCEAR,1982 in Sutherland and de Jong (1990)) because more atmospheric nuclear tests took place in the northern hemisphere (Ritchie and McHenry, 1990). However, local events such as the Chernobyl accident may have significant impact on regional fallout (Bennett, 1994).

Reports from New Zealand, China, Brazil, Zimbabwe, Mexico, Lesotho, Ghana and Niger have shown that the technique can be used in parts of the world outside the northern hemisphere (Quine et al., 1994; Zhang et al., 1994; Basher et al., 1995; Garcia-Oliva et al., 1995; Abekoe, 1996; Chappell et al., 1998). In New Zealand, Basher et al. (1995) obtained values ranging from 587 to 662 Bq m^{-2}, while Zhang et al. (1994) had 1400 to 4000 Bq m^{-2} in China. Values reported for the semi-arid region of West Africa were higher. Abekoe (1996) reported values ranging from 690 to 2267 Bq m^{-2} for Northern Ghana. Chappell et al. (1998) reported values ranging from 940 to 4129 Bq m^{-2} and estimated the local reference inventory to be 2066 Bq m^{-2} for Niger.

2.5.3 Magnetic susceptibility

Although the use of magnetic susceptibility as an erosion research tool is far less developed than the ^{137}Cs technique, it has shown some promise in recent research reports. Moreover the cost of purchase and ongoing maintenance of the measurement systems is less than that for the ^{137}Cs approach and it may be better suited to the research infrastructure in developing countries. The suitability of the technique in highly weathered sub-tropical soils has not, however, been examined in detail and the use of the technique in this study should be viewed as a preliminary evaluation of its suitability in these regions.

2.5.3.1 Background on magnetic susceptibility

Many soils exhibit enhanced levels of secondary ferrimagnetic minerals (magnetite/maghemite) in their upper horizons, detectable from measurements of magnetic parameters, notably magnetic susceptibility (Mullins, 1977; Dearing et al., 1985). Magnetic susceptibility of a substance is defined as the ratio of the magnetization induced in a sample to the magnetic field inducing it. It describes the ability of the substance to magnetize (Vadyunina and Babanin, 1972 ; Mullins, 1977) and can be expressed per unit sample mass (Fine et al., 1989). All substances are magnetically active to some degree, i.e., capable of being magnetized in a magnetic field.

A substance can be described as being diamagnetic, paramagnetic, ferrimagnetic, ferromagnetic or antiferromagnetic (Vadyunina and Babanin, 1972). Ferro-and ferrimagnetic materials exhibit the highest response to magnetic fields whilst diamagnetics exhibit the least (McBride, 1986). Ferro- and ferrimagnetics have highly ordered magnetic materials that respond positively to the application of a magnetic field because all atoms line up in the same direction or two out of three atoms line up in one direction while the third aligns in the opposite direction (Mullins, 1977; McBride, 1986). On the other hand, where alternate atoms have oppositely directed magnetic moments an overall cancellation of magnetism is produced resulting in low magnetic properties. Minerals with that exhibit this behavior are classified as antiferromagnetics (Dearing et al., 1985).

Magnetite, maghemite and pyrrhotite are examples of ferrimagnetic minerals found in soils (Vadyunina and Babanin, 1972), with magnetic susceptibility values of 4 to $10x10^{-4}m^3kg^{-1}$, 4 to $4.5x10^{-4}$ m^3kg^{-1}, and $5x10^{-5}$ m^3kg^{-1} respectively (Mullins, 1977). Lepidocrocite, geothite, hematite have highly ordered magnetic materials, but exhibit low magnetic properties. Lepidocrocite has magnetic susceptibility of 50 to $75x10^{-8}m^3kg^{-1}$ while goethite and hematite have values of 35 to 125 $x10^{-8}m^3kg^{-1}$ and 25 to $65x10^{-8}$ m^3kg^{-1} respectively (Mullins, 1977).

Diamagnetics and paramagnetics have less highly ordered magnetic materials and as a result they exhibit temporary magnetism - they lose their magnetic properties in the absence of a magnetic field. Diamagnetics in the soil such as orthoclase, calcite, quartz, water, and organic matter possess zero magnetic moments with magnetic susceptibility values below zero. For example, the magnetic susceptibility of water is $-0.9x10^{-8}m^3kg^{-1}$

and that of quartz is $-0.6x10^{-8}m^3kg^{-1}$. Their presence in the soil reduces the soil's overall magnetic susceptibility. Paramagnetics have slightly higher positive susceptibility to magnetism than diamagnetics due to the presence of magnetic moments in these substance (Vadyunina and Babanin, 1972; Mullins, 1977). Clay minerals with transition minerals in their structure and organic substances with unpaired electrons often exhibit this type of magnetic behavior (McBride, 1986; Williams and Cooper, 1990), with magnetic susceptibility ranging between -2 to $15x10^{-8}m^3kg^{-1}$. The common paramagnetic substances found in soils are muscovite and dolomite.

2.5.3.2 Controls on magnetic susceptibility of soils

The bedrock from which the parent material is derived provides all the initial magnetic and non-magnetic materials. Sedimentary rocks have the lowest values of magnetic susceptibility, and igneous rocks have the highest values (Mullins, 1977; Brown, 1988). The range of magnetic susceptibility values for metamorphic rocks is intermediate between sedimentary and igneous rocks (Thompson and Morton, 1979). Soils developed from igneous rocks may have lower magnetic susceptibility than the parent material due to depletion of magnetic material at the weathering front (Fine and Singer, 1989) while metamorphic and sedimentary rocks give rise to soils with enhanced susceptibility relative to the parent material (Vadyunina and Koutun, 1974). These differences are related to the differences in size, shape and chemical composition of the soil developed from these rocks. The smaller the grain size, the higher the magnetic susceptibility (Mullins, 1977). A small grain size particle such as clay will act as one stable single domain with high magnetic susceptibility, while larger sized grains of sand will act as multidomain with low susceptibility (Vadyunina and Koutun, 1974). Sedimentary rocks produce soils with high clay content while soils from igneous rocks are predominantly sand. Dearing et al. (1985) suggested mechanical weathering as the mechanism responsible for the release of magnetite into the silt and sand fraction, while chemical weathering results in the accumulation of ferrimagnetics within the finer soil fractions.

Magnetic enhancement of surface soils can be attributed to 1) atmospheric fallout of natural or industrially derived magnetic particles (Maher, 1986), 2) *in situ* conversion of weakly magnetic forms of iron oxides and hydroxides to strongly magnetic magnetite and maghemite (Mullins,1977; Thompson and Oldfield, 1986; Fine and Singer,1989), 3) preferential accumulation of inherited magnetite and pedogenic ferric concretions (Fine et al. 1989) and 4) dilution of magnetic minerals in the illuvial horizon with illuviated nonmagnetic minerals.

The continuous pedogenic development of a soil profile in homogenous parent material may be the most important source enhancement of magnetic susceptibility and a gradual shift from multidomain to superparamagnetic and single domain magnetic states (Fine et al., 1992). Ferrimagnetic material, which is derived solely through pedogenesis, is mostly superparamagnetic and single domain, whereas inherited magnetite are predominantly multidomain grains (Fine et al., 1992). The degree of magnetic activity exhibited by a soil sample depends on the magnetic properties of its constituents. Constituents of importance are ferrimagnetic minerals such as magnetite and maghemite (Oades, 1963). These minerals are secondary ferrimagnetics formed through weathering and pedogenesis, thus soil forming and landscape geochemical processes that favour the release and precipitation of iron are important controls of magnetic susceptibility of soils (Schwertmann and Taylor, 1989; Maher, 1986; Alekseyev et al., 1989; Singer and Fine, 1989).

Transformation of iron compounds can result from oxidation-reduction cycles, dehydration of lepidocrocite, and burning of hematite and goethite (Mullins, 1977;, Maher, 1986). Alternate oxidation-reduction cycles associated with changes in soil moisture favour the production of ferrimagnetics through the mobilization, transportation and precipitation of iron (See Section 2.2.2.4). The oxidation-reduction process depends on organic matter content and heterotrophic microorganisms (Maher, 1986). Organic matter and its decomposition products are highly effective in mobilizing iron, regardless of soil type. The decomposition of organic matter may enhance magnetic susceptibility at the soil surface by releasing up to 3% of the total soil iron.

High organic matter content and heterotrophic microorganisms near the surface may promote formation of ferrimagnetic minerals. Thus in aerobic soils, the bulk of magnetic susceptibility is associated with the Ah or Ap horizons where the released ferrous iron can be reoxidized to its ferric form and resultant mineral species.

Burning of vegetation (Tite and Mullins, 1971) results in the transformation of weakly magnetic materials into ferrimagnetics such as maghemite. The efficiency of fire-induced magnetic susceptibility depends on the soil iron content, soil organic matter content and fire temperature (Brown, 1988). Soils with the highest quantities of organic matter and total iron exhibit very high magnetic susceptibility enhancement upon heating. The combustion of organic compounds produces a reducing atmosphere which leads to the transformation of weakly magnetic iron oxides (weathering products) (Fine et al., 1989). Goethite and hematite are converted to magnetite which may in turn be oxidize to maghemite when air enters the soil upon cooling (Mullins, 1977). Lepidocrocite can dehydrate directly to form maghemite. The magnetic susceptibility enhancement due to burning is expressed most strongly in the top 1 to 2 cm (Longworth et al., 1979; Brown, 1988) since the highest fire temperatures are obtained in the upper 1- to 2-cm depth as compared to the lower depths.

2.5.3.3 Use of magnetic susceptibility to study soil processes

The magnitude of magnetic susceptibility enhancement at the surface and the depth of enhancement below the surface increase with soil age. Deviations from this expected trend may be indicative of a discontinuity in the parent material which could be related to deposition of imported material, erosion or persistence of water logging (Walling et al., 1979; Dearing et al., 1986; Fine et al., 1992).

The variation with depth of magnetic mineralogy provides a quick method for correlation between sediment sources. By matching the magnetic properties of sediments with those of the eroded source materials the sediment sources can be traced (Thompson et al., 1980). Since the distribution of magnetic characteristics within a soil environment reflects the variations in magnetic mineralogy of the transported material, changing erosion rates may also be expressed by magnetic variation within the lake sediments. Sandgren and Fredkseld (1991) used this technique in combination with pollen stratigraphy and carbon dating to document changes in lake sedimentation due to man-induced erosion in Southern Greenland. The mass magnetic susceptibility data reflected erosion events that were results of changing climatic conditions, vegetation and human activities. High values of magnetic susceptibility in the lake sediments correlated with agricultural activities or deforestation that severely degraded the land and produced intense erosion. Low values of magnetic susceptibility in the cores corresponded to periods of plant regeneration, reduced erosion, and milder climates.

Most of the above studies were essentially sediment source tracing. It is believed that the use of magnetic susceptibility in soil erosion studies lies in comparing the topsoil's magnetic susceptibility with that of an uneroded soil and the subsoil. Provided that the topsoil material is magnetically enhanced with respect to parent material, the magnetic susceptibility of the surface soil should be consistently lower in eroded landscapes than for non-eroded soils developed under the same conditions. Depression areas should exhibit higher than normal values of magnetic susceptibility at the surface due to deposition of magnetically enhanced materials from upslope. However, as soil erosion continues, magnetically unenhanced subsoil material from upper slopes will bury the magnetically enhanced soil in the depression area (Brown, 1988; Dearing et al. 1986; Oldfield et al. 1979). Brown (1988) used magnetic susceptibility to characterize landscape segments of chaparral soils in Southern California with regard to erosion patterns. He found that soils low in organic matter content and with low values of magnetic susceptibility were typical of eroded areas. Higher magnetic susceptibility values were associated with more highly developed soils.

It is important to note that the above assumption may not hold for soils with concretionary sub-soil horizons such as those found in the study area. In these soils, as erosion increases the concretionary-B horizon will be exposed. The iron concretions may have enhanced magnetic properties, so that eroded soils may have higher magnetic signals than uneroded soils. Walling et al. (1979) warned that because magnetic susceptibility is related to ferrimagnetic materials, its use for the study of soil processes must be done with caution. The chemistry of iron is very complex; it is easily transformed from one state to another depending on the prevailing soil environment (Sherman and Kanehiro, 1954; Walling et al., 1979; Schwertmann and Taylor, 1989). Because of the sensitivity of iron species to environmental conditions, the interpretation of magnetic parameters is subject to some degree of uncertainty (Oldfield, 1991).

Walling et al. (1979) advised that a well-established relationship between iron and the specific environmental-depositional conditions is needed before final conclusions can be drawn on the efficiency of magnetic susceptibility as a long-term tracer for sediment movement. They emphasized that magnetic parameters can only provide a crude magnetic fingerprint of different types of sediments sources, because iron compounds are so easily transformed by changes in their environment. The survival or persistence of magnetic crystals in the form in which they were deposited is of extreme importance in their use in geomorphological studies.

2.6 Socioeconomic perspectives

Sustainable agriculture requires that effective land use planning should involve identification of farming practices that are soil conserving and understanding the socioeconomic circumstances of the target farmers (Douglas, 1990). The decisions made by the land user on how the land is to be used and whether or not to adopt a specific recommended conservation practice (or to continue with a non- sustainable practice) will primarily be influenced by the socioeconomic circumstances facing the farm household (Swift, 1997; Douglas, 1990). Hence the security, viability, and especially the acceptability aspects of sustainable land management require at least a preliminary evaluation of the socioeconomic context of the farmers of the study region.

The history of agricultural development over the last several decades contain many examples of failures in adoption or continued use of technologies that were judged scientifically sound (Altieri, 1995; Lal, 1987) because socioeconomic conditions of the farmers were not taken into consideration. Examples are the failures of water-management schemes in the inland valley zones of West Africa (Richards, 1985), minimum tillage practices in the same region (Lal, 1987) and soil conservation projects in various countries and the difficulties experienced more recently in promoting the adoption of alley cropping (Dvorak, 1991).

Rural poverty contributes more to decisions based on immediate needs rather than sustainable development (Swift, 1997; Nsiah-Gyabaah, 1996) and it is linked to the wider national and international social, political and economic issues. In order to set the scene for the study, it is important to understand the wider social, political and economic context in which rural poverty occurs. This section, therefore, looks at the international factors that led to rural poverty and then briefly discuss the national agricultural economy of Ghana.

2.6.1. Incorporation of sub-Sahara Africa into the world economy

The history of agriculture development in sub-Saharan Africa can be traced through three different eras of political development: pre-colonial export trade, colonial export economy and the post-colonial state development (Okai, 1992; Woodhouse, 1995). These three eras were characterized by various degrees of commoditization of the basic elements of production, consumption, reproduction and incorporation of sub-Saharan Africa into the world economy (Dixon, 1993; Bernstein, 1995a; Okai, 1992). Associated with each era are specific social, economic and political objectives that have had an immense influence on the pattern of agricultural production and consequently land use in the region (Okai, 1992). As these changes occurred, the economic options available to the farmer changed.

The pre-colonial change in agricultural production resulted from European expansion. This era was characterized by "gathering" of export commodities such as timber and rubber as opposed to their cultivation (Bernstein, 1995a). Other commercial crops (such as oil palm) were indirectly cultivated by selective conservation of oil palm trees during land clearing for food crop production. Oil palm trees then colonized the land during fallow regeneration. Cocoa cultivation followed after the decline of the oil palm industry.

During the colonial export economy, the production of raw materials to feed manufacturing industries in Europe and America was pursued. This export economy influenced the pattern of production in Sub-Sahara Africa mainly through their labour requirements (Bernstein 1995b). The rural areas functioned as labour reserves for the capitalistic enterprises leading to shortages of labour on their own farms especially at key moments in the agricultural calendar (Bernstein, 1995b). The colonial rule forced the rural areas into labour reserves and cash cropping by increasing their requirement for cash through increased taxation and restriction on land use in some instances (Woodhouse, 1995). Increased taxation forced the rural farmers to work for cash instead of working on their own farms. In Sub-Saharan Africa, these labour shortages were more important than shortages of land because land was regulated by customary tenure.

The commercialization of rural life in the colonial economy through crop cultivation for export and labour migration changed the existing forms of communal household organization in a variety of ways. Labour was supplied not only to the mining industry, plantations and white settler farms, but also areas of intensive development of peasant cash cropping, notable in the flow of labour migrants from the Sahelian belt of West Africa to the forest zone in the south (Okai, 1992). During this era, the pattern of development was biased towards urban areas with few railroads leading to the production areas in the hinterlands. Industrialization was limited to some agricultural processing and very few consumer goods.

The era of peasant farming and state development emerged after independence (Okai, 1992). Dissatisfied with the pattern of development in the colonial era, post-independence plans attempted to direct the economy away from foreign capital and markets towards meeting national needs and aspirations. Attempts were made to diversify the narrow export-based economy, to undertake industrialization, and to meet basic needs through provision of education, health and housing. However, the dependence on an export-based economy to support development programs resulted in the perpetuation of the colonial tendencies (Woodhouse, 1995). Some of the actions taken include "modernization" of agriculture through "packages" of new crops or crop varieties, fertilizer, improved cultivation and management practices, credit, etc. (Okai, 1992). But the bargaining power and returns of the small-scale farmer remained low because markets for inputs and outputs were controlled by the state through taxation and the control of prices and marketing. Furthermore, most of these development projects ignored the detailed local knowledge of the farmers, and the standardized packages are often inappropriate for the variable and fragile ecology of most of rural Africa (Bernstein, 1995a). The relatively buoyant economy of the 1950s and 60s gave way to increasing problems in the 1970s and, finally, crisis in the 1980s (Barraclough, 1991).

2.6.2 The agricultural economy of Ghana

Starting with a relatively high income per head at independence and with other economic and social advantages, the country went through a phase of stagnation and sharp decline in the 1960s and 1970s (Bequele, 1983; Hansen, 1987; FAO, 1991) as a result of inappropriate macro-economic policies, compounded by weak overall economic management and a series of adverse external circumstances. Between 1980 and 1983, the situation in Ghana worsened as real GDP declined at an average annual rate of 5%. At this time, the economy was characterized by highly overvalued local currency, low producer prices and excessive Government controls and participation in the economy (FAO, 1991). The adoption of the Economic Recovery Program (ERP) in 1983 reversed the decline in the economy. The introduction of macro-economic adjustment measures and prudent economic policies, including the dramatic devaluation of the currency, had positive results. However, in 1990, the GDP growth fell sharply and the Government's fiscal position also deteriorated.

The economic decline in 1990 was triggered by stagnation of the agricultural sector, first in food and then in cocoa production. Ghana is principally an agricultural country with agriculture making the highest contribution (55%) to the GDP and employing over 60% of the labour force (Benneh and Agyepong, 1990; FAO, 1991). As a result of adverse economic policies of the 1970s and the early 1980s, food crop and cash crop output declined, which, combined with an increasing population, resulted in a decline in the per capita food production index from 100 in 1974-1976 to 62 in 1983. The measures adopted under the ERP have resulted in significant improvement in agricultural output, nevertheless, as growth in other sectors has been more rapid, agriculture's share of the GDP has fallen from 55 % in 1982 to 48% in 1990. In the past, cocoa contributed almost 30% of agricultural GDP, but this has declined to about 9% at present.

According to Hansen (1987), the trend of agricultural development in Ghana provides a very interesting, though tragic, case for study because Ghana seemed to have many advantages ecologically and socially as compared to other countries in the sub-region. Ghana is not an arid country like Niger, Burkina Faso, Mali, Ethiopia, and Mauritania; nor had land been taken away from the rural poor as was the case in Kenya, Algeria or Zimbabwe. There was no settler agriculture like colonial Algeria, Kenya, Tunisia or Zimbabwe, nor plantation agriculture as in Mauritius, Cameroon, Cote d' Ivore or Liberia to interfere with food production. Multinational involvement in agriculture is relatively recent and its impact is very negligible. In addition, Ghana is credited as having a relatively good economic and social infrastructure and a large pool of trained manpower. What then is the problem with Ghana's agricultural economy?.

Ghana's agricultural economy is based on the "peasant model". Over 90% of food and agricultural production is in the hands of small farmers with average holding of not more than two hectares. These farmers are economically and socially disadvantaged. Just like in any other developing country, the small farmers in Ghana live in poverty. National economic policies adopted over the years appeared to have intensified rural inequality and poverty (Bequele, 1983). In the south, social differentiation resulted from inequality in the access to land, while in the north, inequality in regional development was the major element. These are reflected in the local pattern of population, migration, land tenure system, community organization and structure and basic infrastructure presented in the result section.

2.6.3 Poverty and the rural poor

In northern Ghana, the majority of the population still lives in rural areas as members of small-scale farming households (or smallholders) that are ultimately dependent on agriculture for their basic livelihood. Thus the potential of improving the food production lies in the development of the smallholder sector (Douglas, 1990). Conditions in rural areas often vary greatly between seasons and from one year to the next. Life for many entails a daily struggle in which much energy and ingenuity is needed to secure a livelihood in the face of various crises (Bernstein, 1995a).

The description of rural poverty is very complex. It cannot be described merely by listing the symptoms or distinguishing between the rich and the poor as done by economist using measures of land holding, food intake, or income (Dixon, 1993; Bernstein, 1995b). Dixon (1993) argued that poverty varies in depth, and that measures of land holding, food intake, or income can only enable us to draw lines between the very poor and the not so poor, with very little understanding of what those differences mean to the people concerned. To understand poverty from the perspective of the rural poor, descriptions should include their survival strategies (Dixon, 1993). Bernstein (1995a) argues that Chambers (1974), who distinguishes five dimensions or conditions of poverty/deprivation, described rural poverty best:

1. lack of adequate income or assets to generate income, that is poverty in the sense used by World Bank and others,
2. physical weakness due to under-nutrition, sickness or disability,
3. isolation physically and /or socially due to peripheral location, lack of access to goods and services, ignorance, illiteracy,
4. vulnerability to any kind of emergency and contingency, and the risk of becoming even poorer, and
5. powerlessness within existing social, economic, political and cultural structures.

While the first three conform to conventional models of poverty expressed in measurable physical indicators, the latter two are not easy to measure (Bernstein, 1995b). A complete description, therefore, should include access to land and farming implements, to credit and other resources; social relations with others who are richer and more powerful; and employment, as well as the processes that concentrate power and resources creating inequality in the society (Dixon, 1993). These processes operate at all scales, from the international to local.

2.6.4 The economy of rural households

According to Hart (1986) rural households operate in an economy that is neither capitalist nor socialist. He described it as an "economy of affection" because it involves complex networks of support, communications and interactions among structurally defined groups that are connected by blood, kin and community. The system relies on the social relations or relationship between people both within and between households and the physical and human resources that households command to secure livelihoods and reproduce (Crehan, 1995). In this type of economy, the dynamics of the micro structure (internal socio-economic conditions) are important because most households are units of consumption as well as production (Crehan, 1995).

Internal socio-economic circumstances refer to those factors that are internal to the rural households and over which its members have some control (Douglas, 1990). Allocation of land, labour and capital are all internal household decisions. The internal circumstances have a direct influence on the way individual households make use of the land resources available to them and will determine their response to recommendations for improved land use practices. These are described by: (1) the goals of the household, (2) social organization of the household, and (3) organization of the farm household economy (Douglas, 1990).

Douglas (1990) argued that the first step in evaluating land use from the perspective of a rural household is to determine the goals governing their land use decisions. Rural households have multiple goals and soil management is only one small component of a farmer's spectrum of activity. Adequate income and consumption, security, independence and self respect have been identified as some of the important goals of the rural household. In making a decision, the farmer combines his or her knowledge and perceptions of soil-based constraints with an overall appraisal of the potentials and limitations to production in a given year (Swift, 1997).

Swift (1997) and Douglas (1990) stressed that farmers are experts in risk minimization so as to ensure food security. Thus new technologies, whether fertilizer or organic matter-promoting measures that may maximize yield will only be accepted if they are consistent with both income and risk avoidance objectives. Households will deliberately exploit a range of enterprises so that should one fail, the production or cash income from another can sustain them at least on a short-term basis. Crop diversification with the use of drought resistant varieties of different maturing periods, staggered planting dates and mixed food crops with distinct agronomic requirements and production periods hedge against severe losses from irregular rainfall (Swift, 1997). Stability of yield across a range of seasons is more important than maximization of mean yield. As a result, farmers will frequently reject high yielding varieties if they yield less in poor seasons than traditional varieties as they cannot afford in any one year to drop below their subsistence requirements.

The social organization of the rural household has important implications for land use management in particular with regards to labour availability (Crehan, 1995; Douglas, 1990). Smallholder farming relies on labour largely supplied by household members as the most available and flexible factor of production. Family labour is not usually regarded as a production cost as members have to be sustained whether they work or not, but hired labour is considered a drain on scarce cash resources and therefore is sparingly used. Consequently, the amount of family labour available will affect the amount of land that can be cultivated and the timeliness of the various farm operations such as planting and weeding (Woodhouse, 1995; Douglas, 1990). The organization of labour within the household is an important factor determining its production activities. There is often significant specialization in agricultural tasks, enterprises or even crops, among sex and age groups that must be taken into consideration when introducing improved land use practices (Crehan, 1995). Sex or age specialization in certain production activities within the household can cause each group to evaluate land use recommendations differently in accord with their own set of incentives and constraints.

The rural household economy is organized around the various land use enterprises, and is usually supplemented by other income generating activities such as trade and wage labour (Crehan, 1995). Specific land use strategies may serve specific goals and thus it is important to understand the role each plays within the household economy before targeting a particular land use enterprise for improvement. This will determine whether the particular land use will help the household to better meet its goals. For example, there will be little incentive for a household to increase the production of a low value staple crop beyond the family's subsistence level. If the current production practices meet the farmers' subsistence need it is most unlikely that he or she will adopt improved practices. However, they may adopt improvement, for example seed, that will permit them to obtain the same yield from a smaller area with less effort, thus freeing land and labour for alternative enterprises (Douglas, 1990). Within the household economy each strategy is linked and has a degree of interdependence with the other strategies in the system. This interdependence needs to be considered in land use planning, because if improvements to one land use enterprise adversely affects another it may be rejected by farmers. Yield in each may not be maximized but the combined production serves the needs and goals of the household.

3. MATERIALS AND METHODS

There are two components to this study. One involved the characterization of the soils associated with each of the farming systems to determine the systems' effect on soil properties, and to identify soil properties that can be used as soil quality indicators. The second part is a study of the socio-economic conditions and attitudes of the farmers, which include their indigenous knowledge and perspectives on soil conservation and land management.

3.1 Research design for soil quality evaluation

There are many approaches to evaluate soil quality (as discussed in the preceding chapter). The approach adopted for this study was to compare the soil quality conditions under typical agricultural practices to the conditions at an uncultivated site. This approach allows the magnitude and direction of soil quality changes to be assessed by reference to the baseline conditions at the undisturbed site. It does not, however, allow a precise measurement of the rate of change, which would only be possible under a design where distinct treatments were imposed on a landscape and monitored for several years.

This type of undisturbed/disturbed site design has been widely used in soil quality evaluations and the assumptions that underlie it are clearly identified in the literature. Dyck and Cole (1994) argue that the two key assumptions are that 1) all of the ecosystems under study were identical (or at least very similar) at time zero and have not been selectively affected by biological factors since time zero and 2) that the climate has not changed and is similar for all the sites used in the comparison. Assumption 2) can be met by selecting sites in close proximity to each other, but meeting assumption 1) is far more difficult as will be clear throughout this dissertation.

3.1.1 Study site selection

Sixteen farmers' fields in the village of Kugri in the Northeastern region of Ghana were selected for the study. This village was chosen because it had a good representation of the landforms and slopes of major soil association (the Varempere association) in the study area (Adu, 1969). The land use and agricultural practices are typical of the region and, very importantly, there is a site that has never been cultivated to be used as reference point. Most of the other accessible villages within the study area do not have an uncultivated land nearby.

The agricultural practices involved permanent cultivation around the compound houses and shifting cultivation some kilometers away from the households. The permanent cultivation around the house is known locally as compound farming and the shifting cultivation systems are known as bush farming. A land fallow system is used to restore fertility in the bush farms. Detailed description of the farming systems is provided in the chapter that describes the study area.

The treatment units were compound farm (designated as CF), active bush farm (ABF), short-term fallow (STF) and long-term fallow (LTF) and an uncultivated site (UC). The fallow fields were grouped into the two classes to study the effect of length of fallow on fertility regeneration. Short-term fallows are sites that have been in fallow for 1-10 years. Long-term fallows are those sites that have been fallowed for more than 10 years. In the second field season, a compound rice farm (CRF) located at a lower elevation in the area of the compound farms was added, primarily to see if it was acting as a depositional site for the compound farm fields.

The original experimental design was to sample five replicates of each treatment (i.e., compound farms, active bush farms etc.). This design could not be implemented because of the complex variation of the landscape and unavailability of adequate land use history and uncultivated sites. Therefore, sixteen sites made up of two compound farms, seven bush farms, three short-term fallows, two long-term fallows, one uncultivated site and a valley rice farm, were sampled. These sites were distributed within five transects and attempts were then made to stratify these sites according to landscape position. All sites except the compound farm sites were situated about 6 to 10 km from the compounds.

3.2 Field measurements and soil sampling

Eight of the fields (UC, ABF1, ABF2, ABF3, STF1, LTF1, CF1, and CF2) were sampled in the summer of 1996 and the remaining eight sites (STF2, STF3, LTF2, ABF4, ABF5, ABF6, ABF7, and CRF) were sampled in the summer of 1997. In order to trace the movement of ^{137}Cs, most of the sites selected for the second season sampling were located in low-lying areas. At both times, sampling was done in June and July at the beginning of the growing season.

3.2.1.Topographic survey

A magnetic compass was used to set up a 5- by-7 grid on the uncultivated site and long-term fallow, while a 5- by-5 grid was set up on the remaining fields. The grid spacing for all the sites was 25 m. More points were taken in the uncultivated and the 50-year fallow sites because only one of each type of site exists in the study village. For the eight sites sampled in 1996, an Abney level was used to collect topographic information from the grid points in order to evaluate within field variability. For the 1997 fields sampled, the grid point topographic data were not collected since the results from the 1996 field season showed that elevation differences within the fields were small.

3.2.2 Soil profile description and soil sampling

On the two reference sites (UC and LTF1), 12 grid points were described and sampled; on the cultivated sites nine points were used. Point sampling and descriptions were done to study within-field variability. In the first field season, soil samples were collected at five depths (0-5, 5-10, 10-15, 15-20, 20-25 cm) where possible. These sampling depths were used because there was limited information on the properties under study. Based on the results of the 1996 field season, soil samples were collected at only two depths (0-10, 10-20 cm) during the second field season. At each depth, two sampling procedures were used: (a) core sampling for bulk density analysis and (b) bulk sampling ,which involved taking five composite core samples. From some of the central pits, soil samples were taken to the depth of 150 cm to study vertical variation in soil properties.

A central profile pit was dug on each field and used for general description of soil in the field. Soil description was done using the FAO/ISRIC (1990) guidelines for soil description. Parameters described include soil colour, texture, structure, consistency, plasticity, A-horizon thickness, drainage/mottling, depth to concretion, and depth to hardened plinthite. Soil colour was described using a Munsell colour chart.

3.2.3 Vegetation analysis

Because the traditional shifting cultivation practised in the study area depends on natural regeneration of fertility through fallows, the rate of vegetation regeneration was studied. Vegetation count was carried out along a transect across each field using a 1 m by 1 m quadrat thrown at 10 m interval. At each sampling point, the vegetation type and number were recorded. The frequency of occurrence of individual species and density of occurrence were determined. Frequency describes the number of quadrats in which each species was present divided by the total number of quadrats thrown (occurrence per number of quadrats). It is expressed as a decimal fraction or percentage. Density is the number of individuals of that species per unit area (number of individual plant species per unit area). The relative frequency (frequency per total number of specific vegetation type) and relative density (number of individual species per total number of specific vegetation type) were also calculated. Relative frequency describes the spread of species and relative density describes dominant species.

This aspect of the work was done with the assistance of experts from the Institute of Renewable Natural Resources of the University of Science and Technology, Kumasi, Ghana (now known as Kwame Nkruma University of Science and Technology, Kumasi).

3.3 Laboratory analysis

3.3.1 Soil sample preparation and determination of percent concretions

The soil samples were air-dried, weighed, and the aggregates were broken using mortar and pestle, taking care not to crush the concretions. Large concretions were hand picked and the soil with smaller concretions was passed through a 2 mm mesh sieve to separate concretions from soil fines. The concretions were weighed and the percentage of concretions in each sample was calculated on air-dry weight basis. The soil fines (< 2mm fraction) were stored for further analyses.

3.3.2 Particle size analysis and bulk density analysis

Particle size analysis was done on the soil fines following the modified pipette procedure of Indorante et al. (1990). Bulk density of whole-soil (uncorrected) was determined by taking core samples and weighing to record the total weight. A sub-sample was oven-dried and the soil moisture content and oven-dried sample weight calculated. Bulk density was calculated by dividing the dry weight by sample volume. The sample volume was derived from the dimensions of the core sampler.

The bulk density values obtained were corrected for the presence of concretions following the procedure outlined by Vincent and Chadwick (1994). Table 3.1 shows the parameters required for the correction. Most of the soil samples, especially those taken from sites on upper slope, contained large amounts of Fe concretions. For soils containing many coarse fragments bulk density measurement is problematic because results vary significantly with sample volume, and whole-soil density may differ appreciably from the bulk density of fine earth (soil with all fragments >2mm removed) (Soil Survey Staff, 1994). According to Vincent and Chadwick (1994), to accurately determine the bulk density of these types of soils, large sample volumes are required. Because large sample volumes have practical limitations, they presented an alternative approach that determines bulk density from modest-sized samples and corrects for the presence of rock fragment using mass-size distribution from large (> 40 kg) representative disturbed samples, and rock fragment bulk densities.

Total mass of core-sample (MT) was the mass of soil taken from the bulk density core. The volume of sample (VT) is volume of the core sampler (98.12 cm^3). Since the percentage of concretions in the bulk soil samples was known (section 3.3.1), the mass of concretion (M>2) was calculated from total mass (MT) and percent concretion. The mass of fines (M<2) was determined by difference between total mass of the core-sample (MT) and mass of concretions (M>2). The bulk density of the concretions (D_b>2) was calculated following the procedures in section 3.3.3.

Table 3.1 Parameters required for correcting whole-soil bulk density for concretions.

Parameter	Symbol	Units
Total mass of core-sample	MT	g
Mass of concretion (> 2 mm)	M>2	g
Mass of fines (<2 mm)	M<2	g
Volume of sample	VT	cm^3
Bulk Density of concretion	D_b>2	g cm^{-3}

Using these values, the correction proceeded as follows:

1) Bulk volume of concretion (Vbk>2) was determined from mass of concretion (M.>2) and bulk density of concretions (D_b>2):

$$Vbk{>}2 = M{>}2 / D_b{>}2 \qquad [3.1a]$$

2) Bulk volume of fines (Vbk<2) determined by the difference between the total volume of core-sample (VT) and bulk volume of concretions (Vbk>2):

$$Vbk{<}2 = VT - Vbk{>}2 \qquad [3.1b]$$

3) Finally, bulk density of the fines (Db<2) was determined from mass of fines (M<2) and bulk volume of fines (Vbk<2) as follows:

$$Db{<}2 = M{<}2 / Vbk{<}2 \qquad [3.1c]$$

The value Db<2 is the bulk density of the fines corrected for the influence of concretions. Because analyses were only performed on the fine fraction, this bulk density value was used for subsequent calculations.

3.3.3 Determination of bulk density and porosity of the concretions

The bulk density of the concretions was determined by a modification of the method described by Currie (1966). Concretions were washed to remove all soil particles and then saturated with water. The saturation with water was done by placing the concretions in a beaker of water that was then placed in an evacuating dessicator to which vacuum was applied for 30 minutes. After evacuation, the excess water was drained off and the concretions were transferred to 250 mL cylinder with a known volume of water. Volume of the concretions was determined by the amount of water displaced. The saturated concretions were poured onto a filter paper to drain excess water and weighed after which they were oven-dried and the oven-dry weight taken. Since water evaporates very rapidly, the operations from the desiccator to the weighing of saturated samples were done rapidly so as to avoid air re-entering their pores. The porosity and density were calculated using the following equations:

$$\text{a) Total porosity} = \frac{W_{sat} - W_{od}}{V_{sat}} \qquad [3.2a]$$

$$\text{b) Bulk density of concretions} = \frac{W_{od}}{V_{sat}} \qquad [3.2b]$$

where W_{sat} is weight of saturated concretions (g), W_{od} is weight of oven-dried concretions (g) and V_{sat} is volume of saturated concretions (cm^3).

3.3.4 Cesium-137 measurement

Cesium-137 redistribution was measured on the bulk soil by gamma spectroscopy. Soil samples were put in 1-L Marinelli beakers for equilibration and placed over a high-purity coaxial germanium crystal enclosed in a Lucite-lined, 10-cm thick lead castle connected to a Canberra Series 35 Plus Multi-channel analyzer (MCA). Cesium-137 activity concentrations per unit mass (Bequerels kilograms $^{-1}$ (Bq kg^{-1})) were determined by counting the 662 keV gamma emissions between 2 to 21 hrs per sample.

Areal activity (Bq m^{-2}) of a sample was calculated as follows:

$$Cs = Cs_c \times BD \times SD \qquad [3.3a]$$

where Cs is areal activity (Bq m^{-2}) for the sample, Cs_c is the cesium concentration (Bq kg^{-1}), BD is the bulk density (kg m^{-3}) and SD is sampling depth (m). All samples from a given point are summed to provide the total inventory for that point.

The amount of cesium in the uncultivated site was used as a baseline and compared with the cesium in soils at other sites. The redistribution of ^{137}Cs at each site was calculated as a proportion of the input value as follows (Walling and He,1999):

1) The percentage reduction in the total ^{137}Cs inventory for each point was calculated as:

$$^{137}Cs_{net} = \frac{(^{137}Cs_{ref} - {}^{137}Cs_{cult})}{^{137}Cs_{ref}} X100 \qquad [3.3b]$$

where $^{137}Cs_{net}$ is the percentage reduction in total ^{137}Cs inventory, $^{137}Cs_{cult}$ is the ^{137}Cs present at the cultivated sampling point, and $^{137}Cs_{ref}$ is mean value of ^{137}Cs for the native sites.

2) The linear proportional model was used to convert the percentage reduction in ^{137}Cs inventory to rates of soil erosion:

$$E = 10\frac{^{137}Cs_{net} \times BD \times DI}{100T} \qquad [3.3c]$$

where E is the average erosion or deposition rate (t ha^{-1} yr^{-1}), $^{137}Cs_{net}$ is the percentage reduction in total ^{137}Cs inventory, BD is the bulk density of soil fines (kg m^{-3}), DI is the depth increment containing ^{137}Cs (m), and T is the time between sampling and beginning of fallout (T = 33 yrs). This time frame was adopted for uniformity, because of the uncertainty surrounding cultivation history of the sites.

Walling and Quine (1990) described the limitations of the proportional method, particularly relating to the accumulation of ^{137}Cs at the soil surface between cultivation phases, and suggested it may overestimate rates of erosion.

3.3.5 Magnetic susceptibility measurements

Magnetic susceptibility measurements were carried out on approximately 10 g of each sample placed in a 4 dram clear plastic vial (2.3 cm diameter by 5 cm high) to obtain a near optimum fill. Studies have shown that magnetic susceptibility was dependent on height and that a maximum value is at a fill height of about 20 mm (Senft, 1990). The Bartington Dual Frequency magnetic susceptibility meter (Bartington Instruments) was used for the measurements at both low (0.47 kHz) and high (4.7 kHz) frequencies for all samples to determine both magnetic susceptibility (X) and frequency dependence of the magnetic susceptibility X_{fd}. Blank instrument readings were taken prior to and after two consecutive measurements were taken on each sample to account for any thermal drift encountered by the instrument.

The percent loss of magnetic susceptibility $(\% X_{fd})$ with a ten-fold increase in the frequency and absolute frequency dependence magnetic susceptibility was calculated directly from average values of (X) at both high and low values using the following equation: $\% X_{fd} = \dfrac{(X_{lf} - X_{hf})}{X_{lf}} \times 100$ [3.4]

The absolute frequency dependence magnetic susceptibility was calculated by using low frequency (X) values corrected for height and the $(\% X_{fd})$ of the sample. Analysis was done on fines. A few of the concretions were analyzed separately for comparison.

3.3.6 Chemical analysis

Soil pH and electrical conductivity (EC) were determined using a 1:2 soil:water ratio. The samples were stirred to ensure complete soil water contact and allowed to settle before measurement. Sample pH was measured with a Fisher Acuret Model 805 MP pH meter. EC was measured with YSI Model 32 conductivity meter.

Basic cations (Ca, Mg, K, Na) and acidic cation (Al) were extracted using unbuffered 1.0 M NH_4Cl (pH7) and effective cation exchange capacity (ECEC) was calculated by summation of basic and acidic cations. Given the soils' pH and the negligible values obtained for Al, it was assumed that H^+ ions were not present in sufficient amounts on the exchange complex to lead to serious underestimation of the base saturation of the soil and therefore, were not measured. Atomic absorption spectrophotometry (AAS) was used to measure Ca, Mg, Mn and Al in the 1.0 M NH_4Cl extracts and extractable Na and K were measured by flame photometry. Oxalate extractable Fe (Fe_o) was determined by the photochemical extraction procedure outlined by McKeague and Day (1966) and dithionite-citrate extractable Fe (Fe_d) was by the method of Mehra and Jackson (1960).

Total N and P were extracted by H_2SO_4-H_2O_2 digestion described by Thomas et al. (1967). Phosphorus in the digest was measured by colorimetry. Total N was read using glycine as standard on the autoanalyser.

Total C was measured by the Leco CR 12 Carbon Determinator at 1100°C and organic C was determined at 840°C using the same equipment. Inorganic C was taken as the difference between total C and organic C. SOC was converted to Mg ha^{-1} by multiplying the organic C with the bulk density of the fine soil and sampling depth.

3.3.7 Predictive relationships for erosion induced change in SOC with time

The temporal relationship between soil erosion and SOC was predicted using a modeling approach (Kachanoski and deJong, 1984; Kachanoski, 1993). A model was developed that predicts the amount of SOC remaining in the soil as a function of time and erosion rate. Soil loss was calculated from changes in soil ^{137}Cs over time and the model accounts for SOC additions from the subsoil. The model developed for estimating soil loss from changes in soil ^{137}Cs over time assumed that ^{137}Cs was concentrated in the 0- to 15-cm layer of soil with no additions from the subsoil over time. This assumption is not true for SOC. This procedure viewed changes in SOC conceptually as a set of transfers within the soil column and between different parts of the landscape (Pennock et al., 1994). In sites where soil loss is occurring, SOC-depleted subsoil is progressively mixed into the upper layers as soil is removed from the surface. In the depositional sites, aggradation of the soil surface occurs and the organically enriched portions of the soil column increase with time.

Let T_o = total mass of SOC (g m^{-2}) present in the plow layer soil at the time of initial measurements or estimate. The amount of SOC present after 1 yr. of erosion T_1 can be estimated from

$$T_1 = T_o - [(ET_oR)/M] + EC_B \qquad [3.5a]$$

Rearranged as

$$T_1 = T_o\,[1-ER/M] + EC_B \qquad [3.5b]$$

where E is the annual erosion rate (kg m^{-2}); M is the specific soil mass of the plow layer in which SOC was measured (kg m^{-2}); and R is the ratio of the SOC concentration in the eroding sediment to that in the plow layer. C_B is the concentration of SOC (g kg^{-1}) in the subsoil added into the plow layer. The mass of soil lost from the topsoil is equal to mass of soil incorporated from the subsoil, but concentration of SOC in the subsoil is lower. Equation 3.5a assumes that the concentration of SOC remained constant during year 1 and was equal to T_o/M. If at the end of year 1 the remaining SOC (T_1) and subsoil SOC was mixed into the same mass of soil by tillage (tillage dilution), it would follow that at the end of year 2:

$$T_2 = T_1\,[1-ER/M] + EC_B \qquad [3.5c]$$

Equation 3.5c assumes that concentration of SOC in year 2 was constant and equal to T_1/M. Substituting Eq. 3.5a into Eq. 3.5c gives

$$T_2 = T_o\,[1\text{-}ER/M]^2 + EC_B\,[1\text{-}ER/M] + EC_B \qquad [3.5d]$$

Recognising that the same procedure can be continued for *n* years of soil loss gives

$$T_n = T_o\,[1\text{-}ER/M]^n + EC_B\,[1\text{-}ER/M]^{n-1} \ldots\ldots + EC_B\,[1\text{-}ER/M]^{n-n} \qquad [3.5e]$$

The first part of equation [5e], { $T_o\,[1\text{-}ER/M]^n$ } gives the average annual loss of SOC (g m^{-2}) due to erosion as a function of time. The second part { $EC_B\,[1\text{-}ER/M]^{n-1}$ ....+ $EC_B\,[1\text{-}ER/M]^{n-n}$ } provides an estimate of SOC additions from the subsoil.

The following assumptions made were: (1) the rate of erosion would be constant over the years; (2) the bulk densities would also be constant; (3) and the depth of soil lost from the surface would equal to the depth of soil mixed in from subsoil. External inputs would be zero.

3.4 Socioeconomic study

The specific objectives of the socioeconomic study are : (1) to collect background information on the economic and social setting of the study area, (2) to study the indigenous knowledge of farmers regarding soil quality and land degradation, and (3) to understand the farmers' perspective on production risk and strategies they adopt to deal with some of these problems.

Farmers' land use decisions depend on many factors and characteristics. Prominent among these factors are social and economic factors (Stonehouse, 1994) which are under the influence of the wider institutional factors. Institutional factors include government policies and programs, education and extension infrastructure, and the macrostructure characteristic of the agriculture industry. Having regards to the complexity of the issues involved, a combination of methods that have been extensively employed elsewhere (Norman et al., 1983; Carruthers and Chambers, 1985; Singleton et al., 1993) was used. The data collection methods include (a) literature search and collection of data from government offices, (b) informal survey, and (c) household interviews. The literature search and government documents provided background information on the study region. The informal survey collected information on the people and the microenvironment. The household interviews were conducted to collect specific information on land use and resource management.

3.4.1 Informal survey

The informal survey involved interviews with farmers, extension officers, local scientists and policy makers for information on local and regional variables that affect farmers' land use decisions. The interview involved discussions with the following:

i) Deputy Director of Extension Services Department

ii) The Agricultural Station Manager at Manga Savanna Agricultural Research Institute (SARI).

iii) Regional and District Agricultural Extension and Crop Services Officers

iv) The following members of Kugri village and neighbouring villages: a) The Chief of the village, b) The Spiritual Leader of the village, c) The Assemblymen who are political leaders (past and present) and d) Ten households that were selected by the Chief. The selection was based on age of the household head. Since I was interested in land use history, the Chief selected households with older heads. In each household, the head, his wives, his siblings and some of his children were interviewed. Farmers from other communities were casually interviewed where possible.

Questions were asked concerning community organization and structure, organization and economy of the household, land ownership and tenure, land use (crop and livestock system), land degradation, the role of women in the system, nutrition of the farm family, population growth, off-farm activities, access to credit and agricultural support services. This informal survey was useful in establishing a rapport with the local people. Through informal discussions with community leaders and the people, it was possible to have a general overview of the microenvironment and to understand some of the less straightforward, less technical but nonetheless important socio-cultural issues of relevance to achieving the research objectives. It also provided a background on which the household interviews were based.

3.4.2 Household interviews

A questionnaire checklist/guideline (Appendix C) was designed with the participation of faculty in the Departments of Sociology and Soil Science at the University of Saskatchewan. The design of the questionnaire followed the minimum socioeconomic survey approach (Moran, 1989). A final review was carried out in Ghana with the experts in the Extension Service Department of the Ministry of Food and Agriculture. At the final review session it became apparent that the questionnaire was too long for practical purposes. On advice from the experts in the Extension Services Department of the Ministry of Food and Agriculture in Ghana, the questionnaire was broken into three sets for ease of administration. Part one, which covers questions on demographic characteristics, was the same for all three sets. The first set of questions in Part two contained questions on farming practices, land and land availability (to be referred to as farming practice). The second set of questions in Part two covered agricultural services, financial resources and marketing (to be referred to as agricultural services). The third set of questions covered problems encountered in farming and strategies adopted in solving them (referred to as conservation strategies).

The interviews were conducted in Kugri village (the main study village) and nine other settlements in the Bawku district with the assistance of the field staff from the Extension Services Department of the district. Due to the dispersed nature of compound households and the lack of systematic numbering of compound farm houses, a strictly stratified or cluster sampling technique could not be employed. Besides Kugri, the interviews were conducted in the following settlements: Kuka, Kpikpira, Bugwia, Atuba, Basyonde, Garu, Manga, Pusiga and Binduri.

Within each village, eighteen households were interviewed; six answered the set of questions on farming practice, another six answered the set of questions on agricultural services, and the last group of six answered the set of questions on conservation strategies. It should be noted that all the groups answered questions on demographic characteristics (i.e., Part One of the questionnaire). This number was considered the maximum that could be effectively handled within the research budget and time.

No systematic sampling technique was used to select the households to be interviewed but only households that consented to be interviewed were visited. The focus of the interview and the unit of analysis was the 'household' mainly because it is the primary unit of production, consumption and social interaction. In order to understand the decision-making processes of communities and households, the interviews were conducted with the household head or his wife and in a few cases with another member of the household acting as his representative.

3.5 Methodological weaknesses and limitations

3.5.1 Limitations and weakness of the soil characterization component

The major limitation of the research design for this study is the assumption that all sites must have a similar range of soil conditions prior to the disturbance (i.e., initiation of agriculture in this area). This is the key assumption that allows the cultivated sites to be compared to the undisturbed site. In the course of the field investigations it became apparent that a considerable range of soil conditions occurred in the study area, and that the nature of the soil-landform relationship were complex. The attempt to group the sampled sites into meaningful pedological/landform groups became a major focus of the subsequent work, which is discussed in Chapter 5. Arguably a much more complete pedological – landform survey should have been completed prior to the soil quality sampling. The complexity of the soil-landscape relationships only became apparent during the course of field sampling and hence could not have been anticipated at the time of initial research design.

In terms of laboratory analysis, a decision was made to focus on the fine fraction of the soil, rather than the concretions and related forms, although in some cases the concretions were analyzed separately for comparison. Focussing on the fines in this study was based on the understanding that most of the readily available plant nutrients were concentrated in the soil fines, which are more readily lost by erosion. This approach was adopted because the study is focussed on examining the effect of erosion as one of the processes that degrades soil quality. Large-sized particles such as rock fragments and Fe-concretions are neither easily detached nor transported (Poesen et al., 1994). As a result, particle size separation takes place when soil material is eroded by water (Poesen and Savat, 1980; Lal, 1976b). Fine particles are moved out of the system leaving a coarse lag behind. The soil nutrients and exchange sites are concentrated in the soil organic matter and clay fractions, which are associated with the fine fraction (Lal, 1976b).

It is important to note that the coarse lag is also an active fraction especially in adsorbing plant nutrients. Phosphorus is one of the important nutrients adsorbed by the coarse lag which contains high amounts compared to the soils fines (Owusu-Bennoah and Aquaye, 1989; Tiessen, 1991; Abekoe, 1996). Abekoe (1996) reported two to eight times higher total P in nodules than soil fines. However, the soil fines had more labile P than the concretions. Most of the total P found in the concretions was in resistant forms and the short-term availability of the adsorbed nutrients to plant is not clearly understood. Thus concretions were considered to be less active in plant nutrient supply. This assumption may be an important limitation to the study especially for the results obtained for the total P analysis.

3.5.2 Limitations and weakness of the socioeconomic component

Households do not always share common goals or strategies. Household members frequently have a high degree of individual control over the income and environmental resources at their disposal and many conflicting economic strategies (Barlett, 1990). Husbands, wives, children, and other adults in the household can be expected to differ in their opinions about situations. Interviewing household heads or their wife ignored much of this variability.

The arrangement whereby the second part of the questionnaire was split into three sets and each set was answered by different groups of respondents limits the extent to which the data can be analyzed quantitatively. Since the three different sets of questions were answered by three different sets respondents, cross-tabulation of variables can only be done within sets, but not between sets.

The lack of a systematic sampling approach could introduce a bias, as those willing households may not be representative of the entire population. Most often, these people are the most articulate in the society. People vary in their ability to articulate their culture in general and their personal decisions in particular. The most articulate are not necessarily the most representative of a group (Barlett, 1990).

Since the study is essentially for background information collection, these limitations are not expected to affect the validity of the data collected. Furthermore the use of data from other sources is expected to help overcome these limitations.

3.6 Data processing

RockWare mapping software (RockWare, 1994) was used to create Digital Elevation Models (DEMs) for the sites from the survey data. The socio-economic data were examined using frequency distributions, cross-tabulations and chi-squared test using SPSS statistic software package (SPSS, 1993).

The laboratory data were analyzed using descriptive statistics, exploratory data analysis and correlation analysis techniques. This statistical analysis was conducted using SPSS software (SPSS, 1993). The majority of analyses simply utilized box and whisker plots. A box and whisker plot is a simple diagram that describes the distribution of an entire data set. The box or interquartile range represents the absolute value of the difference between the values of the 25^{th} percentile and the 75^{th} percentile. The upper and lower whiskers or fences extend to values, which represent 1.5 times the spread from the median to the corresponding edge of the box. Data points outside these values are considered outliers and are plotted as individual points. Other statistical analysis techniques include correlation analysis, and difference testing. Significance level of 0.1 was used for most of the analyses.

4. SOCIOECONOMIC CONDITIONS IN THE STUDY AREA AND FARMERS' INDIGENOUS KNOWLEDGE AND PERCEPTIONS

The problem of land degradation and soil fertility loss in most developing countries can be linked directly or indirectly to the socioeconomic conditions of the farmer. At the core of the social issues is rural poverty as caused by rapid population growth, insecurity of land tenure, poor agricultural policy, and lack of access to information (Swift, 1997; Altieri, 1995; Bernstein, 1995a; Dixon, 1993; IFAD, 1992; Cook and Grut, 1989). For example, rapid population growth leads to agricultural expansion into marginal lands and shortening of fallow periods (IFAD, 1992), resulting in rapid land degradation. The poor are almost completely dependent on the natural resource base for their basic needs; these resources are diminishing at a rapid rate, thus threatening increased poverty.

To evaluate soil quality from the perspectives of rural farmers it is important to identify the socioeconomic conditions under which they are operating. The farmers' production constraints and capabilities must be well understood in order to develop appropriate technologies that are acceptable to the farmers (Douglas, 1990). It is also necessary to gain the local people's perception of what is happening to the micro-environment because it is at this level that fruitful causal explanations may lie (Dregne, 1990). Moreover, achieving co-operation and local participation in land control and rehabilitation requires the study and analysis of local people's beliefs, knowledge, interests and perceptions of the environment and resources (Douglas, 1990). The intent of this section is to move away from the classic explanation for degradation (which has been to blame depletive resource use, land mismanagement, and a general resistance to change and innovation on conservatism, ignorance and irrationality of peasant farmers). to instead gain an insight into some of the social and economic reasons behind degradation of the environment.

4.1 Socioeconomic background for northeastern Ghana

In northern Ghana the majority of the population lives in rural areas as members of small-scale farming households that are isolated physically and lack basic amenities such as roads, electricity, water supply and health facilities (Bernstein, 1995a). The income generated from farming activities is often not adequate and most farmers have to rely on other sources of income (IFAD, 1992). As such the farmers focus more on their immediate needs and are often uninterested in new technologies. According to Swift (1995) the fundamental goal of the rural farmer is food security which is achieved by risk minimization strategies.

Insecure land tenure systems and low commodity prices are disincentives to protection or improvement of agricultural lands (Cook and Grut, 1989). Traditional or customary land tenure has been cited frequently as an important barrier to development and as a contributory factor to ecological degradation (Bonsu, 1981; Hudson, 1981; Wangia and Prato, 1994) because of the insecurity of tenure. Insecurity of tenure discourages private investment in resource conservation. As well, because the farmers do not hold legal tenure over the farmlands they have no collateral to raise a bank loan to improve the soil. There is a perception that land that is communally owned is often abused (Hudson, 1981). Firewood, for example, is harvested without due consideration to the harm that an individual's collecting habits have on the local environment. Apart from the insecurity of tenure, land fragmentation associated with traditional tenure is yet another major constraint to soil conservation because soil conservation programs are difficult to implement on small parcels of land (Wangia and Prato, 1994). Inadequate agricultural extension services, bush fire control and deforestation are other important problems that have been cited as reasons for widespread poor land management in rural areas (Hudson, 1986).

The study region is located in the extreme northeastern corner of Ghana, roughly between $10^{\circ}30'$ and 11° north latitude and 0° and $0^{\circ}\ 55'$ west longitude and covers about 5200 km^2. It is bounded on the north by Burkina Faso, on the east by Togo, on the west by the Sisili River and on the south by the Gambaga scarp. Administratively, the region is divided into six districts from east to west: Bawku East, Bawku West, Bongo, Bolgatanga, Navrongo and Sandema. Each district is made up of a number of villages and settlements with scattered compounds and farms.

In general, the Upper-East region, especially the rural areas, is inadequately served with basic social facilities because of a development strategy biased towards urban development (Nsiah-Gyabaah, 1996). About 90 percent of the settlements are not linked with all-weather roads, and an average distance of 4.2 kilometers must be traveled in order to reach a trunk road (Ghana Highway Authority, 1996). The most important road in the region is the heavily pot-holed trunk road that links the border town of Bawku/Kulungugu in the north to Tamale and the rest of the country. The health delivery system is also one of the poorest in Ghana. The region has only about 4 percent of the health institutions in the country (Ministry of Health, 1996). There is no qualified pediatrician; the ratio of patients per physician is very high.

The rural water supply is also woefully inadequate to meet the needs of the population. The most significant water supply program has been the introduction of boreholes and wells under a Canadian-sponsored project (Nsiah-Gyabaah, 1996). These wells are only useful in the rainy season (June - October). They dry up during the dry season during which period women travel long distances for water. Guinea worms and bilharzia contaminate most surface supplies. For the rural population, the use of hand pumps for domestic water supply is the most practical and economic solution. The long-term solution of the water problem may lie in the provision of pipe-borne water to areas of population concentrations.

Most of rural areas have no electricity supply except for the regional and district capitals and some bigger settlements. Under the national government's rural electrification program the majority of the rural areas are expected to be electrified by the year 2000. A lack of electricity and the high petroleum prices discouraged rural agro-industrial production and were key factors influencing deforestation (firewood) with the consequences of accelerated land and environmental degradation.

The region is predominantly rural. About 87% of the total population live in rural areas i.e., in localities with a population of less than 5,000 inhabitants (Statistical Services Department, 1984). Another important characteristic of the region's population is its extreme youthfulness, which reveals a "bottom-heavy pyramid' structure especially in the rural areas. Also, the number of women and the elderly out-number 15-44 year old men. Men in this age group constitute the major productive force of any economy. As such a high social and economic dependency in the socio-economic system is experienced in economies deprived of this group of men. The high dependence ratio increases the need for investment in social services such as education, and health.

Migration accounts mainly for the pattern of population distribution. The whole of Northern Ghana, and in particular the Upper East and Upper West regions, has been an out-migration region for a very long time (Bernstein, 1995a). Rural to urban migration is the dominant type of mobility taking place within and out of the Upper-East region. In the migration flow, it is mainly the able-bodied men between ages 15 to 44 years who are moving out of the region. Women, the very young and the elderly are left behind for the greater part of the year.

4.2 Socio-economic context for the study area: Survey results

4.2.1 Demographic and educational status

Household heads are older members of the family and they are typically male which accounts for the gender and age structure of the respondents in the socio-economic survey (Table 4.1). Because the survey target group was household heads, there was no respondent who was 25 years or less. Seventy-nine percent of the respondents were more than 45 years old and the majority of them are male (89%). In each household, there are about four to five sub-families, depending on the number of men in the household. Some men, especially the younger sons, move out to build their own households close to the main house, but most of them remain in the main household. It is only in the case of death of the male household head and in the absence of a responsible male child that the widow becomes the head of the household.

Most of the families are polygamous. In this study about 71 % of the male respondents had more than one wife, however, with education, this trend seems to be changing (Table 4.3 to 4.5). Older men with less education had more wives than younger men. The number of children per respondent varied from 1 to 25 (Table 4.2). About 50 % of the respondents had between 6 to 10 children.

Table 4.1. Distribution of respondents by age and gender.

Age	Total	Male	Female
25 or less	0	0	0
26-35	3	3	0
36-45	35	31	4
46-55	60	47	13
56-65	48	46	2
66 or more	34	34	0
TOTAL	180	161	19

Table 4.2. Number of children per respondent and marital status of male respondents.

Characteristic	% of Total
Children per respondent	
1-5	26.1
6-10	47.2
11-15	16.1
16-20	8.4
21-25	2.2
TOTAL	100.0
Marital status of male respondents	
More than one wife	70.8
One wife	28.6
Never married	0.6

Universal compulsory education was introduced in Ghana in 1960 with education provided as a free service by the government. In spite of this, the Upper East region still shows 86% illiteracy rate for the rural areas, 55 % for the urban areas and 82 % for the whole region (Statistical Services Department, Ghana, 1984). The results (Table 4.3) of the formal survey are consistent with the above report. Only about 25 % of the respondents had any form of education, which confirms the earlier observation that the region has one of the lowest levels of education in the country. The form of education most of them had was only up to primary school level. However, there seemed to be hope for the future as indicated by the significant ($chi^2 = 72.8$) relationship between education and age (Table 4.4). The relatively younger respondents had more education than the older respondents.

Table 4.3. Formal educational status of respondents

Education Status	% of Total
Never attended	75.5
Primary school	16.7
Secondary school	2.8
Post-secondary	3.3
TOTAL	100.0

Table 4.4. Cross-tabulation of education with age

Age	Never Attended	Primary School	Secondary or More
26-35	1	1	2
36-45	12	14	8
46-55	44	15	0
56-65	44	5	0
➢ 65	34	0	0
➢ Total	135	35	10

$X^2 = 72.8$

Table 4.5. Cross-tabulation of level of education with marital status.

Number of Wives	Never Attended #/135	Primary School #/35	Secondary& more #/10
1	30	10	9
2	35	17	1
3	39	3	0
4	14	2	0
6	1	0	0
7	1	0	0
NA	15	3	0

NA = Not applicable (either female, not married or no response)

4.2.2 Occupational structure

Agriculture is the main occupation of the region's population providing the mainstay of the regional economy. In the formal survey 97% of the respondents consider farming as their major occupation, with crop production as the main farming activity. Livestock keeping is seen as an inseparable complement to successful farming. Other minor activities such as crafts and charcoal burning are important sources of income and employment for the household. The majority of respondents (83%) had off-farm employment. The chief minor occupation of males was hunting. The off-farm activities of women include housekeeping, pito (local beer) brewing, pottery, shear nut butter, basket and charcoal making. Pito brewing from sorghum is the predominant economic activity for women in the region. Trading and agricultural subsidiary jobs such as corn milling are other common occupations of women. An important off- farm activity of younger men is migration to the south to work in cocoa farms and other economic ventures; the older men undertake black smithing and collecting fuelwood for sale.

4.2.3 *Land tenure system*

Ninety percent of respondents acquire farmland through the community or family inheritance (Table 4.6). In most of Sub-Sahara Africa, traditionally, the basic principle of land tenure is communal ownership by clans or lineage (Lovejoy and Sanders, 1994), although there is a trend towards nuclear or individual ownership. Land is held communally with user rights granted by the spiritual leader of the community. Access to land is basically by kinship or birthright; land use rights are passed patrilinearly. Land ownership is vested in the lineage and no one can dispossess a landholder or his family as long as he cares for the land (Saul, 1988). In theory, no member of the family is "landless" because of the principle of communal ownership but in practice there is limitation on type of land use (Saul, 1988). Migrant farmers may be granted use rights on a temporary basis, which restricts the farmer to cultivation of seasonal crops. Re-planting programs allow farmers to farm in the forest reserve; in return they are expected to plant trees.

The majority of respondents (75%) felt that the land tenure system is fair to all and land acquisition is not a problem. It was recognized that access to land is becoming very difficult. Native lands for expansion are almost non-existent and the only source of extra farmlands is fallow land; fragmentation and scattered holdings are increasing as indicated by 98% of respondents (Table 4.6). Most farmers have fragmented holdings, often more than 3 km apart. The main reasons for fragmentation (Table 4.6) given by farmers include the lack of land due to population increase (43%), the system of community/family land allocation (37%), and crop type (20%).

The tenure system discriminates against women as only male children inherit land. Women ordinarily do not inherit or control land directly. The woman normally farms on the land owned by her husband or father. They may have access to land for their own benefit at the pleasure of the father, husband or spiritual leader. A wife's first responsibility is to her husband's farms. Cultivation of her own plot is done only after she meets her husband's labor requirements. Women usually farm groundnuts, cowpea, vegetables and rice. There are quite a few women-headed households due to the seasonal immigration of males to the south. In such cases, labor availability limits the farm size of women to less than about one hectare.

Table 4.6. Source and ownership of land

Question	% of Total
Source of Land	
Community/Family inheritance	90.0
Rent	6.7
Government	3.3
TOTAL	100.0
Land ownership	
Individual	8.3
Family/community	88.3
Government	3.3
TOTAL	100.0
Access to land	
Easy	75.0
Not easy	25.0
TOTAL	100.0
Rating of tenure system	
Good	91.7
Bad	8.3
TOTAL	100.0
Land fragmentation	
Several small plots	98.3
One big plot	1.7
TOTAL	100.0
Reasons for fragmentation	
Lack of land closer	43.3
Community/family	36.7
Crop type	20.0
TOTAL	100

4.2.4 Land use and farming practices

Compound and bush farming are the predominant systems of farming. Compound farming involves farming around the immediate vicinity of compound houses, while bush farms are located about 6 to 10 km from the compounds. Bush farms vary between 1 to 2 ha. On the bush farms, no manure is applied and the farming system is shifting cultivation where fertility is restored naturally through fallow. The length of fallow depends on population pressure on land. In sparsely populated areas, long bush- fallow systems are dominant while short fallow and permanent cultivation is practiced in densely populated areas.

Farmers use both organic and chemical fertilizer as well as improved seeds (Table 4.7). Compound farms benefit much more from organic manure than the bush farms. Ninety-three percent use organic manure on compound farms compared to 5% on their bush farm farms. A minority of respondents believe that the bush farms have better fertility status and do not need fertilization, while others cited the long distance traveled to the bush farms or lack of organic manure as the major constraint to organic manure use on the bush farms (Table 4.8). Most inputs such as chemical fertilizers and improved seeds were readily available (Table 4.9) but they are expensive. Pesticide use is not very common, except on high value crops such as dry season onions.

Livestock, particularly cattle, are kept as a reserve of wealth and insurance against famine. Animal rearing is generally on free range. However, animals are not allowed to roam freely until crops are harvested. Before harvesting, the animals are herded to communal grazing lands. Grazing areas adjacent to villages are shared. Bullocks are an important source of draft power. All farmers use bullock ploughs for land preparation, with seventy percent of respondents owning bullocks and the remaining 30 % rely on rentals (Table 4.7). All other farm operations are done manually. In virtually every home poultry is kept. Other animals reared include sheep, goat and pig.

Table 4.7 Farming practices on compound and bush farms.

Farming practice	% of Total
Use of animal manure on:	
Compound farm	93.3
Bush farm	5
Use of chemical fertilizer on:	
Compound farm	33.3
Bush farm	50.0
Others	
Improved seeds	78.3
Pesticide	35.0
Tractor	0
Bullock plough	100
Own Bullock	70

Table 4.8. Reasons for limited use of organic manure on bush farms.

Reasons	% of Total
Not available	50.9
Too far for transportation	31.6
Better fertility	17.5
TOTAL	100.0

Table 4.9. Availability of chemical fertilizer and seeds.

	Fertilizer	Seed
Timeliness	% of Total	% of Total
Readily	66.6	68.3
Sometimes	16.7	16.7
Rarely	16.7	15.0
TOTAL	100.0	100.0

Crops grown include early and late millet, sorghum, cowpeas, vegetables and rice. A multiple cropping system is practiced for the sake of insurance. Crop mixes of early millet with late millet, late sorghum, and beans are common. Groundnuts and maize are cropped alone. Groundnuts are grown on lands with low fertility. Most valley bottoms are used for rice production in the wet season and gardens of onion and tomatoes in the dry season. Other crops include okra, garden eggs and leafy vegetables.

Family labour is generally the rural household's primary production input and one over which they have most control and can allocate with greatest flexibility (Douglas, 1990). The need for extra labour has been widely cited as the main reason for polygamous families and large number of children per family in most rural communities (Saul, 1988). Participation in farm activities is gender and age related. Male children herd the livestock, while the girls draw water and collect firewood and fruits. In addition to taking care of the household, adult females carry out the planting and harvesting of produce. Adult males carry out major farming activities such as land preparation and weeding. This division of labour is reflected in the lack of a significant relationship between the number of children and the use of communal/cash paid labour on the farm (Table 4.10). Because the younger children do not work directly on the household farm, and young adults migrate down south, their number does not have any direct influence on availability of farm labour. Outside help is employed in the form of communal/cash paid labour. Labour from relatives and friends is known as communal labour. This type of labour is paid for in-kind with food during the work period and reciprocal action. Most often, people from other villages supply cash-paid labour. The most important activity for which outside-help is employed is weeding.

4.2.5 Agricultural services

Access to, and experience with, the local agricultural support services influence farmers' decisions regarding the adoption of particular land use practices. Local agricultural services in the form of extension education and credit facilities are important to adoption of new technologies. Regardless of how good an improved land use practice may be under research conditions, it is unlikely to be adopted without an effective extension service (Douglas, 1990). Two recent studies of

Table 4.10. Cross-tabulations of number of children and the use of outside labour for farm activities.

	Use of non-family labour			
	Land preparation		Weeding	
Number of Children	Used	Not Used	Used	Not Used
1-5	10	3	13	0
6-10	10	9	18	1
11-15	4	10	12	2
16-20	4	3	6	1
21-25	4	2	5	1
NA	1	0	1	0
Total	33	27	55	5

soil conservation in Saskatchewan confirmed the strong relationship between adoption of some soil conservation practices and extension services (Boehm, 1996; Kowalski, 1997).

The Ministry of Food and Agriculture is represented in the region by all of its departments (Crop Services, Animal Production, Veterinary, Plant Protection and Regulatory Services and Extension). The services rendered in the region by the Ministry of Food and Agriculture include training and demonstration of improved farming practices (indicated by 66% of respondents), input supply (20 % of respondents), credit facilities (8%) and veterinary services (5%). The Ministry of Food and Agriculture has promoted a number of changes that affect farming practice in the region. Some of these recent changes are the introduction of improved varieties, chemical fertilizers and agrochemicals, and planting in rows.

The Farmers Services Company (FASCOM) was established in 1978 under the Upper Region Agricultural Development Project (URADEP) to provide physical resources for farmers. Under this program, Farm Services Centers (FSC) were established throughout the region to serve as a chain of retail outlets for agricultural machinery hiring services, fertilizer sales, crop storage, and marketing services. FASCOM operated under a deferred payment scheme to ensure purchasing power of farmers. Due to problems of generating sufficient capital for the seasonal operations, FASCOM is now concentrating on wholesale marketing of fertilizer. Other programs like the International Fund for Agricultural Development (IFAD) support women groups. The Global 2000 project and the Presbyterian Church Farmers Program also assist farmers with input supply. These programs assist farmers with inputs like fertilizer, agrochemicals and seed, with the repayment made in kind, that is with agricultural produce. The Global 2000 program, however, is no longer operating due to farmers' default in repayment of loans.

Since the majority of rural households have little ready cash resources that they can use for investment in improved farm practices (such as purchase of improved seed, fertilizer and farm implements) the input supply and credit facilities of local agricultural support services are very important. In order to benefit from these schemes, farmers are encouraged to form associations or to be members of a cooperative, and hence questions were asked relating to their membership of any such organization. About half of the respondents belonged to some form of farmers' association. The other half did not respond to the question. Of the half that responded, about 60% find their membership very useful. Benefits of membership were loan and input acquisition, exchange of ideas and communal assistance. The presence of the Ministry of Food and Agriculture is, therefore, very strong in the region; 98% of respondents are aware of its existence, while 91 % have benefited from its services.

4.2.6 Marketing and financial resources

The primary objective of the rural farmer is subsistence, after which some of the produce is sold to meet other financial obligations (Table 4.11). The percentage of produce sold generally varied between 5 % to over 20 %. Existing marketing channels and the seasonal and annual variations in price are important factors that determine what and when to produce and the sale of produce (Douglas, 1990). Farmers were asked about the problems faced in marketing of produce. While 28% of respondents felt there are no problems associated with marketing (Table 4.11), a greater number felt the contrary. Problems faced in marketing of produce include low produce price (38% of respondents), poor road network and transportation (30 % of respondents), and storage pests (3%). Solutions suggested by respondents to these problems include good marketing and pricing policy, better roads, storage facilities and formation of cooperatives.

Compared to the number of people per household, the number of financial contributors per household is small (Table 4.12). The main source of the household's income is agriculture supported by off-farm employment. The male member of the family is the main provider supported by the wife or wives and remittances from children working outside the region.

4.3 Farmers' indigenous knowledge and perceptions

Indigenous knowledge is defined as learned ways of knowing and looking at the world (Chambers and Jiggins, 1987). It evolves from years of learning and the social interaction of groups of people of a particular society as they meet the challenges they face in their local environments (Chambers and Jiggins, 1987). It is this local knowledge that enables the farmer to order his/her work within the overlapping cycles (human and natural, controllable and uncontrollable) of the life of a farm (Kloppenburg, 1991). Studies show how farmers' knowledge provides a continuous flow of understanding and experiences about the whole farming system of their locality (Chambers and Jiggins, 1987); their capacity and ability to experiment and their capability to innovate and adapt to ever changing environments (McCorkle, 1989). Indigenous knowledge is adaptable to its physical and human ecology, and consequently its elaboration and improvement is more likely to be environmentally and socially appropriate than outside or exogenous innovations (McCorkle (1989).

To determine the level of awareness of soil quality and degradation, exploratory question centered on two main themes were asked:

Table 4.11. Percentage of farm produce marketed and problems associated with marketing .

	% of Total
Marketing of produce	
All for sale	0.0
All for home consumption	13.3
Sale and home consumption	86.7
TOTAL	100.0
% of produce sold	
5-10	43.3
11-20	45.0
>20	11.7
TOTAL	100.0
Marketing problems	
Low price	38.3
Transportation	30.0
Storage pest	3.3
No problem	28.4
TOTAL	100

Table 4.12. Financial resources available to the farm household

	% of Total
# of financial contributors	
1-5	68.3
> 5	31.7
TOTAL	100.0
Sources of income outside agriculture	
Trade	58.3
Employment outside the region	26.7
Charcoal	8.3
Hand craft	6.7
TOTAL	100.0
Respondents that had access to credit	45

(1) how the respondents perceive the state of their individual farms and that of the village as a whole, and (2) what they perceive as their production risks and problems. These questions were based on the assumption that local people's perception of degradation will be based on socio-economic interest and that they will attempt to control degradation when they know that their physical environment is deteriorating (Stocking, 1981).

4.2.1. Evaluation of the current state of farmland

The farmers are aware of the state of their land (Table 4.13). The word soil, land and earth are synonymous among the people of the area. The soil is associated with a life that cares as in the local expression 'my mother earth'. Questions relating to soil quality always attract spontaneous outcry about the extent to which their farmlands are depleted. They used expressions such as "the land is tired or exhausted" and "the land is old" to indicate the poor state of their land.

In the formal survey, about 95 % of respondents noticed some change in their agricultural land while the remainder think there was no change. Of the 95% that noticed change, 80% were of the opinion that the land has become poorer, while the remainder feel it has changed for the better. Almost all the respondents noticed a decline in yield of crops from both compound and bush farms (Table 4.13). But the compound farms are considered the most degraded, which is consistent with the results obtained from analysis of the soils (Chapter 6). The farmers are of the opinion that continuous cultivation arising from population increases and shortages of farmland has a large share of blame. Certain cultural practices such as ridging along the slope, gathering and burning of plant residue on farms before land preparation and tree felling are also factors.

Table 4.13. Perception of current condition of farmland compared to conditions 30 years ago.

	Compound farm	**Bush farm**
Current condition	**% of Total**	**% of Total**
Own farm		
Bad/worse	80	48.3
Better	18.3	21.7
No difference	1.7	6.7
No response	0	23.3
TOTAL	100	100.0
Neighbour's farm		
Bad/worse	58.3	58.3
Better	10.0	10.0
No difference	31.7	31.7
No response	0	0
TOTAL	100.0	100.0
The village farmlands		
Bad/worse	75.0	41.7
Better	18.4	23.3
No difference	3.3	8.3
No response	3.3	26.7
TOTAL	100.0	100.0
	Yield decreases	
Yes	91.7	71.1
No	8.3	28.9
TOTAL	100.0	100

4.3.2 Local Soil Assessment

The land has multiple functions and local farmers have different criteria for classification. Colour, moisture, sand, gravel contents, rock outcrops as well as workability, vegetation and animal indicators, slope, and landscape position were used by local farmers to classify the land (Table 4.14).

One of the local classification systems of the Kusaasi tribe is based on gravel/concretion content of the soil. Zigi refers to gravel and kuga, kukom and koba are modifiers that refer to high, moderate and low gravel contents, respectively. In the Kusaasi dialect, upper slope soils are known as Zigikuga, middle to lower slopes are Zigikukom, and the river valley and flood plain soils are Zigikoba. Heavy clay soils are known as Yak. Other intermediate soils (probably related to landform) are Tambisi and Tempelug.

In the Zigikuga, the gravel part is always greater than the soil fines. A soil of this nature cannot retain water for a long time and is, therefore, referred to as "dry soils". According to the farmers the best time to work on these soils is soon after a rainfall otherwise the gravel impedes working in the soils. The colours are basically red to brown. The soils are prone to erosion and rock outcrops are common. Acacia are usually found growing naturally on such soils. Zigikoba, found along river valleys or floodplains are considered the best soils. Water retention is good as well as workability. The colour is brown or black.

Middle slope and some low land soils (Zigikukom) are grey, shades of red, and brown. The gravel content is low and sand is predominant. The water holding capacity is very poor, but they are easy to work. At depth in the soil, the Zigikoba soil type is usually found. Yak soils are grey to dark grey in colour and are located in footslope and valley positions. The colour of the baobab trunk is used as reference of grey. The deeper layers are from brown to yellowish white.

Table 4.14. Indicators used to describe soil quality locally and their relative importance as indicated by the percentage of the total respondents that use them.

	% of Total
Indicators of good native land	
Vegetation	58.3
Soil colour	20.0
Vegetation and soil	21.7
TOTAL	100.0
Indicators of a good active farmland	
Crop yield	38.3
Soil	36.7
Weeds, especially *striga*	25.0
TOTAL	100.0
Indicators of a good fallow land	
Vegetation re-growth	48.3
Weeds, especially *striga*	41.7
Soil	10.0
TOTAL	100.0
Indicators of a very degraded land	
Stones and concretions	58.3
Vegetation	41.7
TOTAL	100.0

Yak soils are easily flooded and are very clayey, muddy, and sticky (can easily grasp footwear). In the dry season they crack and come out in big lumps. There is no gravel except in deeper layers.

Tambisi is a mixture of sand and silt with a high proportion of sand going down to about 30 to 40 cm, where clay or gravel is found. They are found in middle or lowland areas that are undulating. The surface temperatures are high in the hot season and the heat can be felt on the soles of the feet. They are easy to work but again water holding capacity is low. Tempelug is dominated by sand and is usually underlain with stones and rocks about one meter or more deep. They are dotted in the lowland areas. Water holding capacity is very poor. These soils are of no economic value to farmers, but they are good as building material.

A productive soil is described as a soil that shows an expression of "fullness with water". The soil should be able to retain moisture without flooding for about four days after a day's rainfall. In this state the soil is said to be able to "breathe", which is an acceptable state of fertility to the farmer. Breathing refers to good drainage conditions in the scientific language. Other important features of fertility include the presence of soil fauna like millipedes, centipedes, scorpions, and worms, organic matter and absence of signs of serious erosion.

Those who have ancestral ties to the early settlers tend to have access to the best land (Saul, 1988). The chief's family occupies the flood plain of the Kugri Mountain catchment where sites ABF6 and ABF5 are located. These soils are locally placed in the Zigikoba group and are the best soils according to local tradition. Soils at sites ABF2 and ABF3 were described as poor soils because they cannot breathe well. The local farmers indicated that these sites are only allocated to migrant farmers.

Local farmers are also aware of the variation in soil fertility and natural vegetation. The presence and devastating effect of *Striga* spp. is another indicator of soil quality used by farmers. *Striga* spp. is a parasitic weed commonly known as the witchweed. It is very common on infertile land and survives by attaching itself on the root system of the host plant. Farmers regard *striga* as having "a toxic tongue that licks up the soil nutrients" leaving the crops to starve. The presence of *striga* on a piece of land is a sign of severe degradation.

4.3.3 Production risks and problems

The responses in the preceding sections show that rural people are aware of problems they face, especially those that affect their farm income and rural energy supply. They are also aware of visible landscape changes such as deforestation and soil erosion. When asked if there had been any major changes relating to crops grown, land tenure, and input prices, farmers were quick to list their problems (Table 4.15). Soil fertility decline was the number one problem, followed by lack of agricultural inputs. Land availability was the third critical problem. Agricultural information was not considered a problem.

Local people have a perception that the productivity of crop land is dwindling yearly. Decreases in crop yield were related to declining soil fertility, continuous cultivation, inadequate fallow periods, and lack of fertilizer. Pastures were also becoming quantitatively and qualitatively poorer as a result of bush fires and prolonged droughts, and it is becoming increasingly difficult to feed animals, especially in the dry season. Farmers mentioned crop losses and famine, which has plagued the region since the late 1960s, particularly during the Harmattan season. They are also aware of the causes of these problems and the possible solutions. For example, for fertility decline, the majority of the farmers cited continuous cultivation without adequate fallow as the main cause. Erosion and bush burning were cited as secondary causes. From the technological point of view, the application of chemical fertilizers is a key solution to the problems but poor distribution, increasing cost of fertilizers, and low rural incomes limit their use by small farmers. A fertilizer subsidy was suggested as a solution by most of the farmers.

Table 4.15. Problems faced by farmers (60 respondents) ranked according to the importance placed on them by farmers.

	Rank			
Problem	**1**	**2**	**3**	**4**
Declining soil fertility	37	17	3	3
Lack of land	18	7	29	6
Lack of inputs	5	33	22	0
Lack of information	0	3	6	51

Ranking 1= most important 4=least important

Other frequently mentioned problems are bad weather, rainfall variability, drought, and bush fires. Most of them believe that bad weather and erratic rainfall were the two most critical environmental problems facing agriculture. While bush fire was also a serious problem, pest and disease attacks were of less concern to farmers because they were infrequent and severe cases were rare. Like other Savannah regions of Ghana, indiscriminate bush burning is one of the challenging issues. Burning is embedded in the cultural value and traditional practice of the people and is an important means of land clearing for crop production. Herders burn off vegetation to make room for tender, green forage readily available to animals and hunters burn to flush out game. Even though pasture research has confirmed the positive effect that infrequent burning has on productivity of grasses (Nye and Greenland, 1964; Innes, 1977), frequent and uncontrolled burning is harmful to both vegetation and soil. Fires set each year throughout the Savannah and woodland destroy genetic resources and organic matter, which protect the soil from erosion and replenish the soils. The fires kill natural regeneration, expose the soil to erosion and destroy crops. Fortunately, most farmers believe that the incidence of bush fires is lower due to controlled burning.

Charcoal burning, fuel wood collection, residue management and the activities of migrant farmers are other activities that lead to land degradation. Charcoal processing is a major off-farm activity undertaken by women and men. Most of the charcoal produced is not used in the village but rather sent to cities for sale. Sixty eight percent of respondents believed charcoal burning has increased (Table 4.16). Fuel

Table 4.16. Charcoal making and fuel wood collection

	% of Total
Household involvement in charcoal making	
Involved	16.7
Not involved	83.3
TOTAL	100.0
Intensity of charcoal making	
Increased	68.3
Not increased	31.7
TOTAL	100.0
Source of household fuel wood	
Own land	1.7
Community land	38.3
Both	60.0
TOTAL	100.0
Availability of above compared to the past	
Easier	10
Difficult	90
Same	0
TOTAL	100.0

wood is needed for fire in the village and women do the collection. Previously, they only relied on dead and fallen wood, but in recent times, these are not readily available and hence they cut wood that is standing leading to exposure of the soil and erosion. It is becoming increasingly difficult (90% of respondents) to get fuel wood in the immediate vicinity of the house and farms (Table 4.16). Longer distances were traveled into the bush to get wood. Crop residues are used for fuel and sometimes as roofing material. Thus, crop residues are not left on the soil to conserve the land from erosion during the long dry periods and the onset of rains.

The activity of migrant farmers was another social phenomenon that was constantly mentioned as one of the problems in the region. Migrant farmers (i.e., people from other communities and the cities) acquiring land in a community not their own have no commitment to the land (Hudson 1981, 1986; Saul, 1988). If prices fall, they abandon the farming enterprise, leaving the land exposed to erosion. Most often, these migrants have more financial resources to clear large expanse of land. Hudson (1981, 1986) also identified this as an important factor that adversely affect soil conservation in most African countries.

The traditional tenure of communal ownership of land had been cited as a major constraint to soil conservation programs (Hudson, 1981). Therefore, questions were asked to ascertain the willingness of farmers to practise conservation on communal lands. The lack of incentive to practise conservation on communal land was clearly illustrated by the fact that only 18% of the respondents indicated having participated in communal conservation programs (Table 4.17). Lack of proper conservation arises from the historical pattern of freely using communal land (Wangia and Prato, 1994; Douglas, 1990).

Table 4.17. Percentage of the respondents that use conservation practice on their own farm and/or on community land.

Type of Soil conservation measure	**PRACTISED SOIL CONSERVATION** YES % of Total	NO % of Total
	On own farm	
Contour farming	46.7	53.3
Stone line	25.0	75.0
Tree planting	75.0	25.0
	On community land	
(any of the above)	18.3	81.7

4.3. Summary of socioeconomic conditions in the study area

The study area is located in the Upper-East region, which is one of the poorest regions in Ghana in terms of financial resources and basic infrastructure. The region is essentially rural with settlements made up of residential compounds and farms. Financial resources are very limited. The rural population relies on farming as the main source of income; however, the farming is done on a subsistence level, supported by off-farm activities.

The main farming systems are compound farming and bush farming. Compound farming involves permanent cultivation around the houses, while bush farming involves shifting cultivation. Bush fallows are used to restore fertility on the bush farms, while household refuse and animal manure are used on compound farms. Credit facilities are limited or non-existent, except where there are projects such as Global 2000 and IFAD credit schemes. The income generated from these sources is barely enough to cater to the basic needs of the farmers; as such it would be impossible for these farmers to make any capital investment in soil conservation measures.

Basic infrastructure such as hospitals, schools, markets and roads are very limited. Long distances are traveled to hospital and most rural residents rely on traditional health healers. Markets and road networks may provide incentives for increased production and investment in proper land use. With very little access to market, farmers will continue producing at a subsistence level. The limited number of schools can be seen in the low educational status of the rural population. This means that extension education can only be provided by extension agents who can speak the local dialect. Where there are no extension agents competent in the local dialect, a community will suffer from lack of extension information. There is hope for the future as the majority of the younger generation has some form of formal education. With the current government policy of education for all by the year 2020, more schools are being built at the rural areas, and the educational status is expected to improve.

Land is communally owned with user rights given primarily to male members of the family. The communal land tenure system may pose a major problem for soil conservation because of tenure insecurity, land fragmentation, and the gender bias allocations policy that are associated with it. Insecurity of tenure does not provide incentive for investment into conservation practices, while fragmentation hampers watershed management projects. Changes to the current land tenure system, however, may be difficult since the majority of the population is content with the current arrangement. The gender-bias land allocation system discriminates against women, in that they do not have direct access to land. Most often they work on their husband or father's farm and only have access to very degraded lands.

Most families are polygamous and the main source of farm labour is family and community members. However, the majority of the able-bodied male emigrate to the south to work on cocoa farms and other sectors of the economy, leaving only the older males and very young children and women behind. Some of the young men come back during the farming season whereas others come only occasionally. This means that any conservation measure that requires intensive labour may not be well received by the rural community. The timing of the labour requirement should also be considered in development of the conservation practice.

The Ministry of Food and Agriculture is an important source of information and used to be the major supplier of agricultural inputs. Most farmers have access to extension information through agricultural extension agents. However, the messages that are being extended to the farmers lay more emphasis on agronomic practices such as planting in rows, and fertilizer applications. The soil conservation messages are neither included nor emphasized. It is believed that this problem would be addressed by the Land and Water Management Project of the Ministry of Food, which was started in 1995. As part of the privatization process in the country, the input supply services have been relinquished to the private sector, resulting in reduced use of input such as fertilizer due to the increased cost, leading to reduced income.

The farmers are very much aware of their environment and have developed certain strategies to overcome their problems. This indigenous local knowledge can be very useful in the assessment for soil quality. For example, the knowledge of land ownership can be used as a guide to land capability classification. In this study, it was observed that the royal families were on the best land and visitors were given the poorest lands.

5. PHYSICAL ENVIRONMENT AND PEDOLOGY OF THE STUDY AREA

The emerging definitions of soil quality imply that soil quality has two distinct components: an intrinsic component related to inherent characteristics of the soil and a dynamic part influenced by the soil user or manager (Carter et al., 1997; Karlen et al. 1997). Dynamic soil quality defines those soil properties that change over relatively short time periods in response to human use and management (Carter et al., 1997). Inherent characteristics of the soil (such as mineralogy and particle size distribution) are those properties under the control of soil forming factors such as climate, landform, water systems and vegetation. Susceptibility of a land to degradation is related to inherent properties of the soil and hence site information on these factors is essential to soil quality evaluation (Arshad and Coen, 1992).

The balance between random variability and systematic variability in soil properties cannot be *a priori* established in a given landscape type. Many studies have shown that soil processes vary according to the various segments of the landscape. For example, in soil redistribution processes, soil removal is typically more intense in the upper slope position while deposition is predominant in the lower slope position. In recognition of this landscape-scale variability in soil properties, this section describes the physical elements and pedological characteristics of the study area so as to provide a background against which changes in dynamic soil properties can be assessed. The first two sections draw upon existing literature to establish the climatic and geological framework for the research region, whereas the remainder of the chapter is based on primary research in the study area.

5.1 Climatic conditions

The region is characterized by semi-arid conditions of long dry periods and short rainfall seasons. The total annual precipitation is about 150 cm (Adu, 1969); the rains usually begin in May and reach a peak from July to September and the dry season occurs between October and April (Fig. 5.1a). Temperature varies very little throughout the year. Average daily maxima are highest in March and April and lowest in August. Monthly mean maximum temperatures recorded are mostly around 35°C and the mean annual temperature is about 27°C (Fig 5.1b)

5.2. Geology and soils

The study region is underlain by three main rock types: Birrimian, Granitic, and Voltaian rocks (Adu, 1969). Birrimian rocks represent the Pre-Cambrian basement complex commonly known as "greenstone". These complexes consist mainly of phyllites, schists, and related rocks mixed with granitic materials. Granitic rocks, which consist of biotite and hornblende complex, are the oldest of the three groups. Voltaian rocks are associated with later formations of the early Carboniferous age (Ahn, 1974), and consist of massive sandstone overlying various beds of mudstone, limestone, and shale. Soils formed from the Birrimian complexes are much more varied and chemically richer than soils over Voltaian formations (Ahn, 1974). The best agricultural soils are those derived from Birrimian greenstone and granite, making areas where they occur the most densely populated (Adu, 1969). Voltaian formations on the other hand, produce very poor sandy or silty soils.

The landscape of the area has a complex geomorphology and soil pattern. Slight changes in slope present dramatic soil differences. Under Ghanaian conditions, soil series rarely cover a sufficient area in individual expanses to make it practical to map them on small scale maps; they are combined into larger assemblages known as associations (Adu, 1969). A soil association is defined as a group of series formed from related parent materials and possessing a similar morphology but differentiated by relief and drainage (Adu, 1969). The major soil associations within the region are the Tanchera, Kolingu, and Vampere associations (Gana, 1996). The dominant soil association in the study area is the Varempere association, which occurs on the Birrimian rocks.

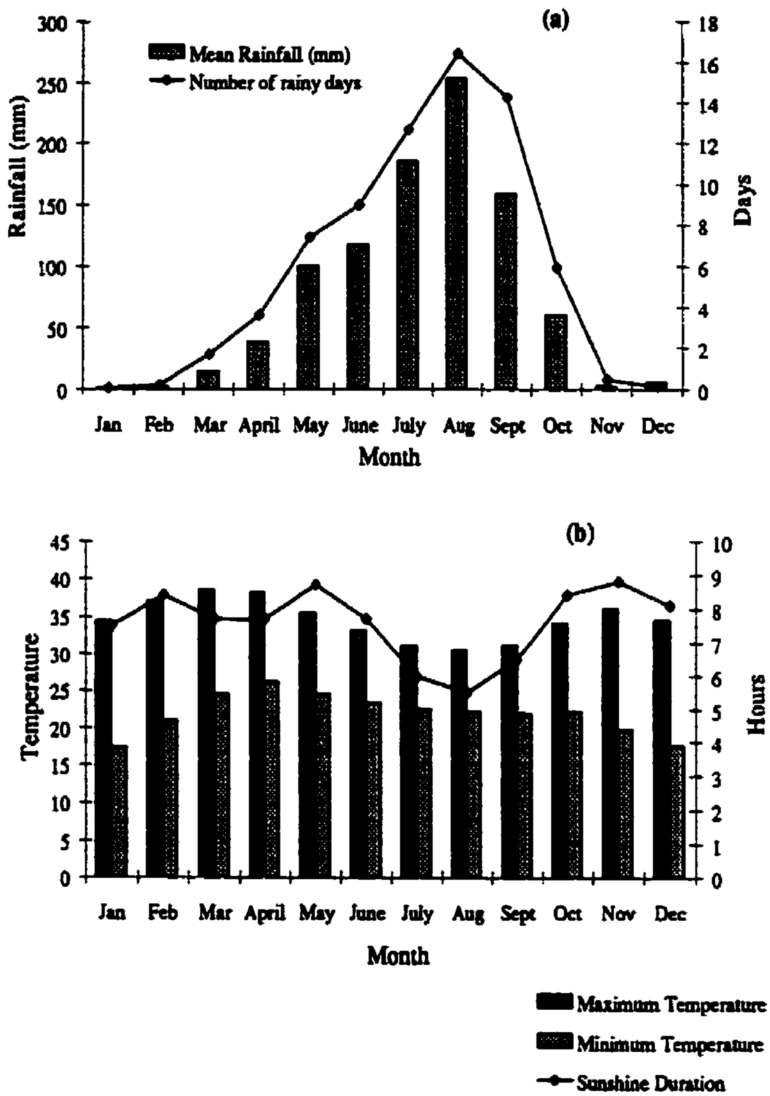


Figure 5.1: Monthly mean (a) rainfall and (b) temperature values for the study region (taken from Adu, 1969).

The Varempere soil association is made up of a series of soil types that show a definite relationship to relief. The uplands are dominated by Alfisols with ferruginous concretionary B-horizons (*Varempere series*). These soils are classified locally as Savanna Ochrosols (Brammer, 1962) and as Plinthustalf in the U.S.D.A system (Soil Survey Staff, 1994). Eroded summits often have iron concretions overlying massive indurated subsoil known as *Hilun series* or capped sheet ironpan classified as *Wenchi series*. Colluvial soils occur on the middle slopes, which appear to be intergrades between the well-drained upland and imperfectly drained lowland conditions. The well drained colluvium or hill wash, which is classified as the *Tafali series*, consist of brownish or reddish yellow, coarse, deep, sandy loams, underlain by quartz gravel, stones, iron concretions or seepage iron pan. Poorly drained midslope soils also occur and are classified as the *Gulo series*. They are shallow, pale yellow, coarse loamy sands that overlie a seepage iron pan, typically with silty clay textures. These sites are often ponded in the rainy season because of their low infiltration capacity. The soils at these sites are classified as Gleysols (Adu, 1969) or Tropaquepts (Soil Survey Staff, 1994). On the lower slopes, alluvisols or colluvial soils, with weakly expressed profile characteristics occur. The soils are gray poorly drained alluvial clays classified as the *Kupela series* and sands as the *Berenyasi series*.

5.3 Pedological characteristics of the research fields

5.3.1. Spatial distribution, land use, and soil landscape relationships

Sixteen research sites were selected according to landscape position and land use for the study. The 16 research sites were clustered in five transects (Table 5.1 and Fig. 5.2). Along each transect the specific sites were chosen to represent the range of slope positions that occurred. Site and profile description was done in the field according to FAO/ISRIC soil description guide (1990). A summary is presented here. The detailed description is provided in Appendix 1. Horizon symbols consist of one or two capital letters for the master horizon and a lower case letter suffixes for subhorizons.

Table 5.1. Location of the research units in the study village within northeastern Ghana.

Site	UTM Coordinates (m)
Transect 1	
UC	792017 E., 1195976 N.
ABF1	792056 E., 1195781 N.
ABF2	791929 E., 1196126 N.
STF1	791957 E., 1195820 N.
ABF4	791584 E., 1195873 N.
Transect 2	
LTF1	794224 E., 1196306 N
ABF3	794538 E., 1196514 N.
Transect 3	
CF1	798702 E., 1193184 N.
CF2	799517 E., 1194670 N
CRF	798310 E., 1193292 N
Transect 4	
STF2	791175 E., 1195491 N.
LTF2	791227 E., 1195491 N.
STF3	791304 E., 1195461 N.
Transect 5	
ABF5	797468 E., 1195339 N.
ABF6	797473 E., 1195247 N.
ABF7	797063 E., 1195220 N.

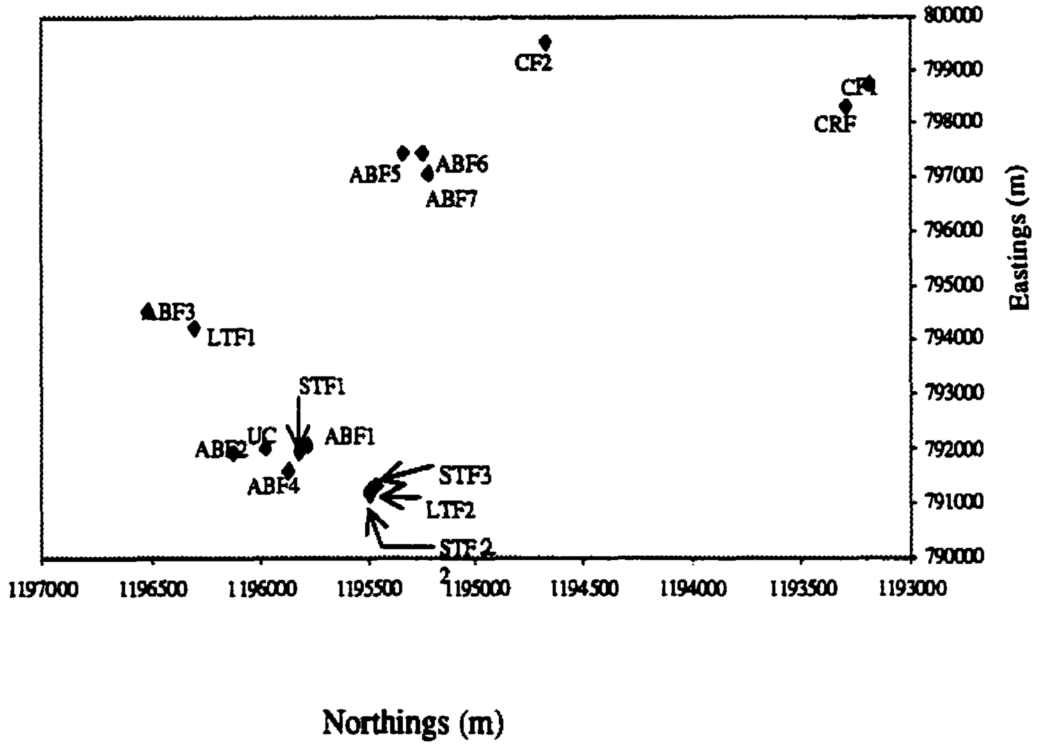


Figure 5.2 Spatial distribution of research units within the study area. Locations were recorded using a single-unit GPS and are an average of 30 minutes of readings.

The master horizons encountered were A, B and C and transitional horizons such as AB and BC. The subordinate characteristics within the master horizons were p (ploughing or other disturbances), c (concretions), t (accumulation of silicate clay), g (strong gleying), and x (fragipan). A Bcx or Btcx horizon forms a major impediment to root growth due to its unfavourable physical properties and hence the depth of this horizon from the surface is a major inherent soil quality characteristic.

The position of each site along the transect was recorded. The transects were similar in length (generally 600 to 900 m, but only 120 m for CF1 to CRF) and the relative position of each site along an idealized transect was calculated (Figure 5.3). This presentation facilitates the comparisons between the slope positions for the different sites. The exception to this is transect 5, which was located in a local catchment as discussed below.

Transect 1

There are five sites (UC, ABF1, STF1, ABF4 and ABF2) in this transect. Transect 1 has a 9 m rise over a 400 m long slope. UC has not been cultivated at any time in the memory of the villagers. ABF1 is an active bush farm that had been cultivated for four years at the time of sampling and was planted with late millet and cowpea. ABF2 had been in cultivation for seven years and STF1 had been in fallow for four to five years at the time of sampling. ABF4 had been cropped for four years at the time of sampling and was rented by migrant farmers.

ABF2 is in a lower slope position with a 4 m elevation rise over 110 m (Fig. 5.4). The A-horizon thickness ranged from 5 to 8 cm. Gleyed horizons (i.e., B_2gt or B_3gtc), indicative of seasonal waterlogging, were observed at 6 of the 9 sampling points. The gleyed horizons typically had orange (7.5YR 6/8) mottles in a duller matrix (Appendix A1). Concretions occurred at a range of depths within the profiles. For example, at sampling point B2 concretions were very common at all depths whereas at sampling point D4 there were no concretions until 75 cm depth.

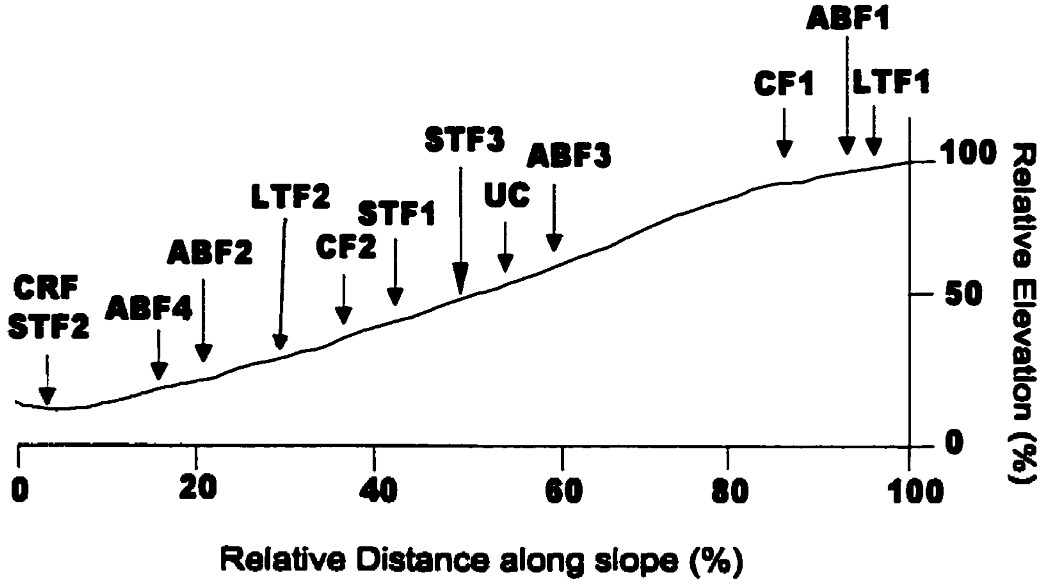


Figure 5.3: Generalized transect showing location of research sites. The transects ranged in length from 400 to 900 m and had elevation gains of 2 to 3 % (i.e., 2 to 3 m per 100 m of horizontal distance).

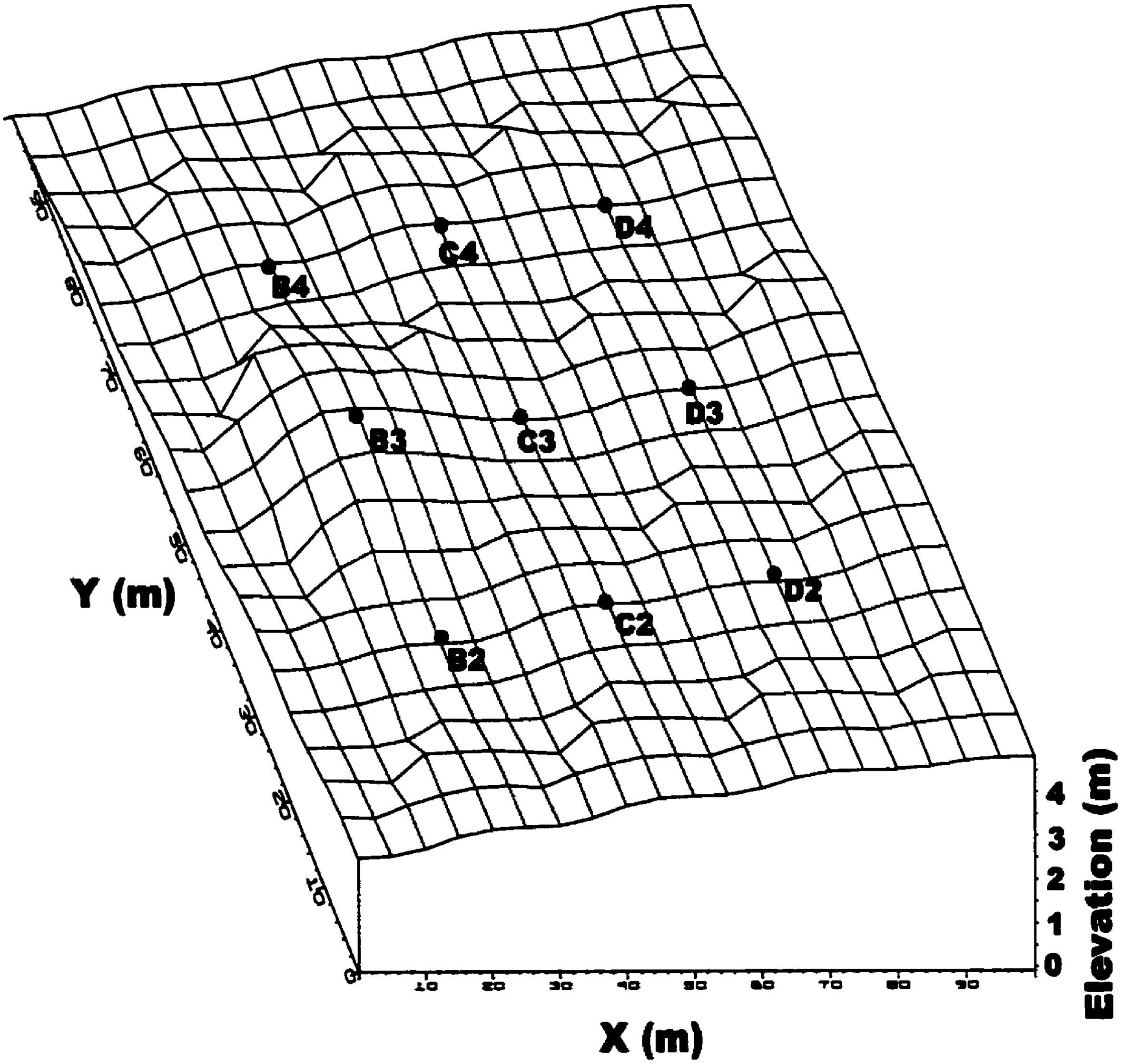


Figure 5.4 Digital elevation model of ABF2 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

The concretions did not seem to be related to the micro topographical variations at the site. This observation is consistent with the expectation that the region had undergone several cycles of erosion, making the macro and micro relief very complicated.

Site UC is in a mid slope position. It slopes from the highest elevation at sampling point F2 to the lowest point at sampling point C4 (Fig. 5.5). The micro-topography is very limited (i.e., the slope is relatively smooth). The soil is generally a sandy loam. The surface A-horizon thickness varies from 6 to 11 cm. Soil colour is typically 5YR or 10 YR 2/1. Below the A horizon, concretions occurred in varying amounts depending on the depth from the surface. The A_2 horizon is similar in characteristics to the Ah horizon except that it has less organic matter and therefore is slightly lighter in colour. Btc horizons occur at most sampling points reflecting the higher clay content and concretions in these horizons.

The lowermost horizons were even more concretionary and sometimes massive and were designated as Bcx. The Bcx horizons occur at a range of elevations from highest (2F) to lowest (4C) (Fig. 5.5). In seven out of the 12 sampling points within this field, massive concretions occur at depths between 25 to 62 cm from the surface. Most of the lowermost horizons have abundant concretions and distinct orange (7.5YR 6/8) mottles in the sandy clay loam matrix. Sampling points C4, F4, E3, and F3 had mottles throughout the profile.

ABF1 is in an upper slope position and has the highest variation in micro-topography (Fig. 5.6). Depth to Bx was also highly variable as was observed in UC. At some sampling points (e.g. C4), which is at the lowest elevation, the Bx horizon was only 24 cm from the surface. Two sampling points (D3 and D4) at micro-rises did not have Bx horizons within 65 to 70 cm of the surface. The variability in micro-topography was not reflected in Apc horizon thickness (Appendix A1).

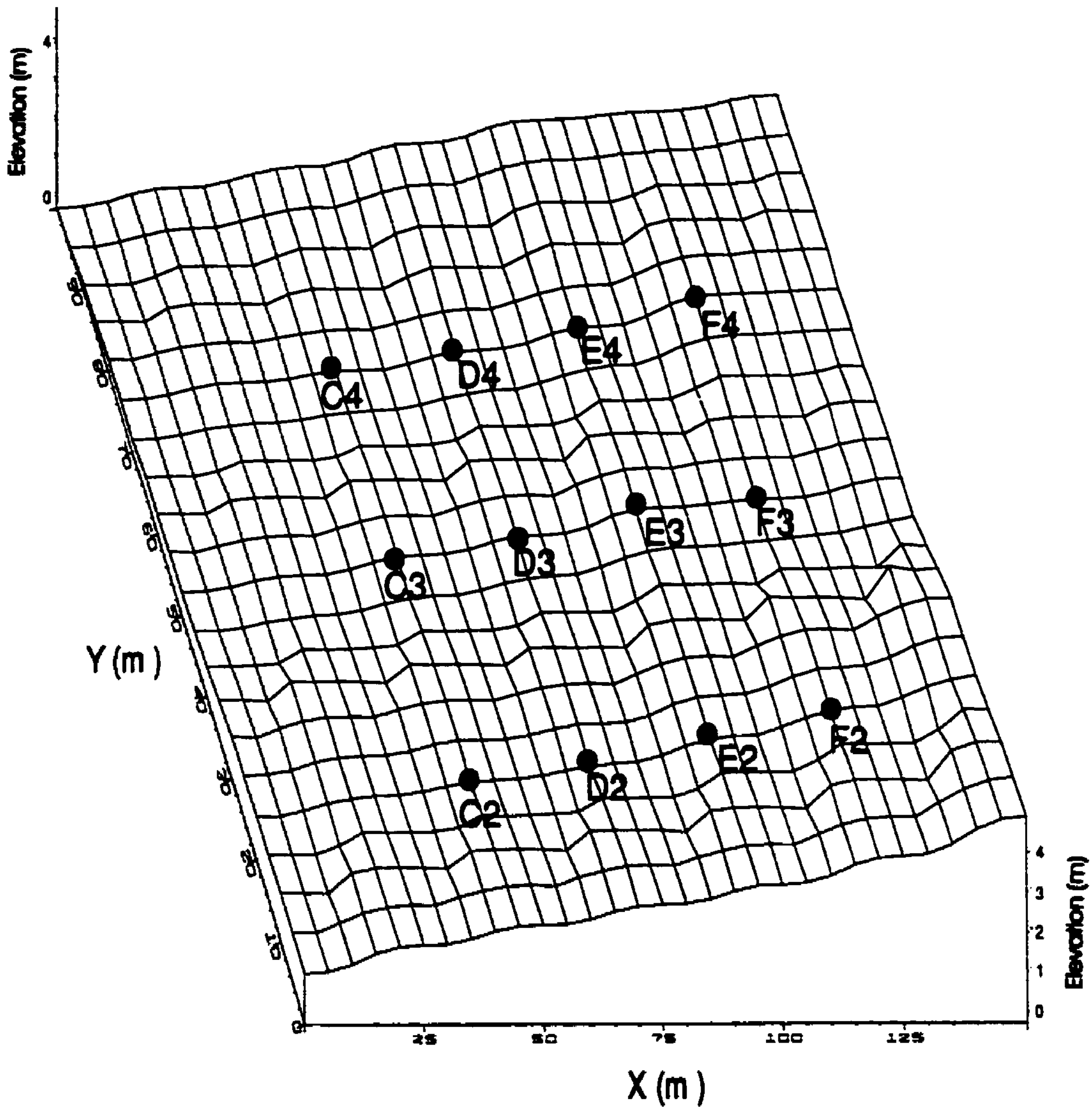


Figure 5.5: Digital elevation model of UC showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

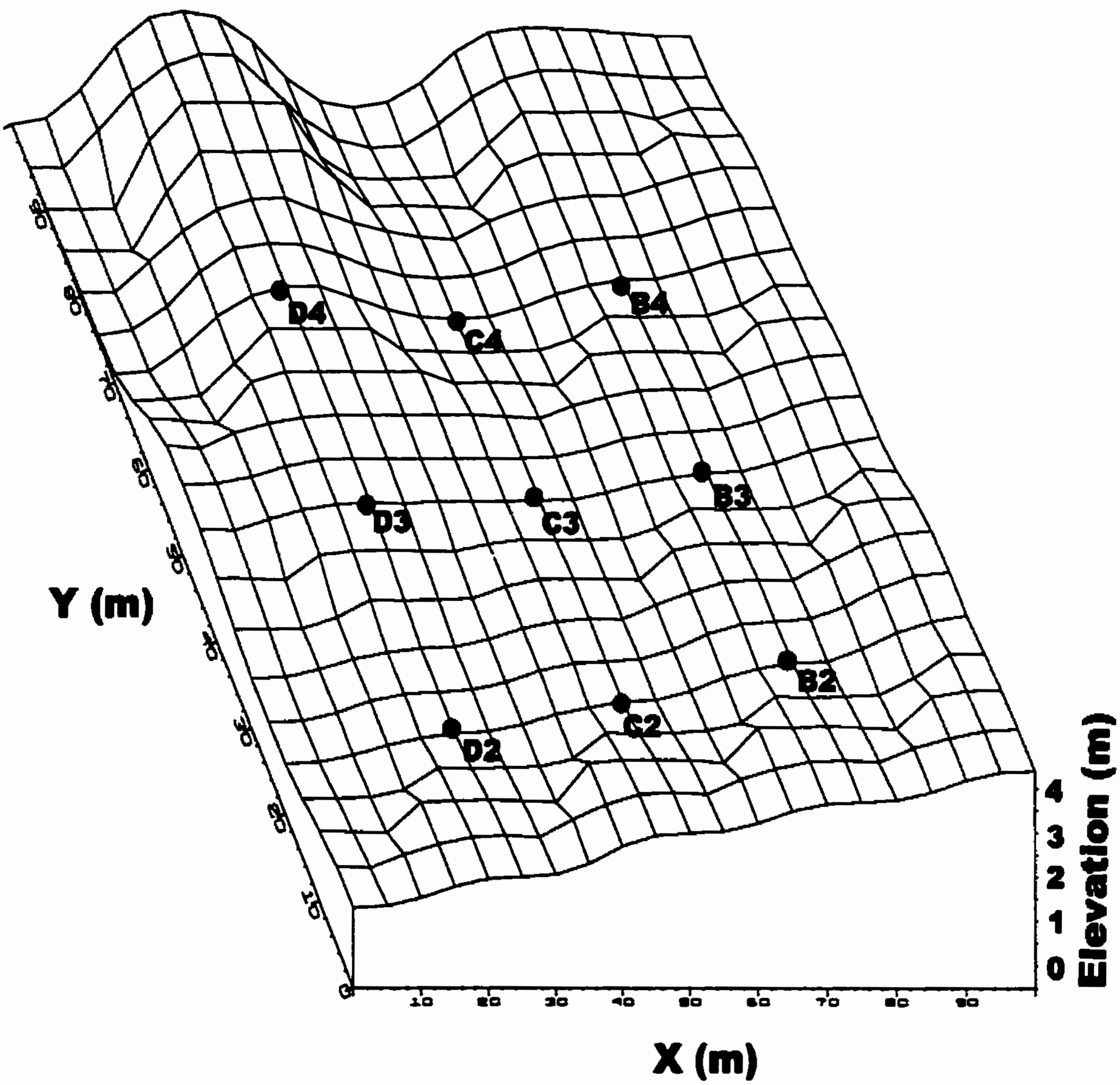


Figure 5.6: Digital elevation model of ABF1 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

The thickness of the A horizon varies from only 5 to 7 cm with many to abundant concretions, underlain by transitional ABc or B_1tc. horizons. Lowermost horizons are dominantly Bx horizons.

Site STF1 is in the mid slope position with limited microtopography (Fig 5.7). The A-horizon varies from 7 to 11 cm thick, with common to abundant concretions (Appendix A1). There are mottles in $B_t$tc horizons at four sampling points but these had no clear relationship to microtopography. Nor did the depth to the Bcx horizon - depth to Bcx is 19 cm at B4 (lowest elevation) and 17 cm at D2 (highest point). All the sampling points have Bcx at depth, ranging from 17 cm (D2) to 58 cm (B3).

ABF4 is also in a lower slope position located 50 m away from the other sites. The soil at this site is sandier than those at other sites. The colour is yellowish to greyish with mottles at depth and there are no concretions to 30 to 40 cm depth (Appendix A1). ABF4 is located at the base of a long slope but still has a linear slope form overall (rather than a concave lower slope position).

Transect 2

LTF1 and ABF3 were on the second transect. LTF1 is a long-term fallow that had been in fallow for more than 50 years. ABF3 is an active bush farm, which had been in cultivation for about eight years at the time of sampling and was planted to a millet and cowpea intercrop.

LTF1 is an upper slope site with 2.5 m rise over 100 m distance (Fig. 5.8). There is a large anthill close to sampling point D2. LTF1 has a very consistent A horizon thickness from 5 to 7 cm thick (Appendix A1). Ten out of the 12 sampling points had Bcx horizons, which were generally less than 35 cm from the surface. At sampling point C2, the Bcx horizon was as close as 24 cm. Only the two lowermost points, B3 and B4, did not have a Bcx horizon. Most of the sampling points had mottles irrespective of the micro-elevation.

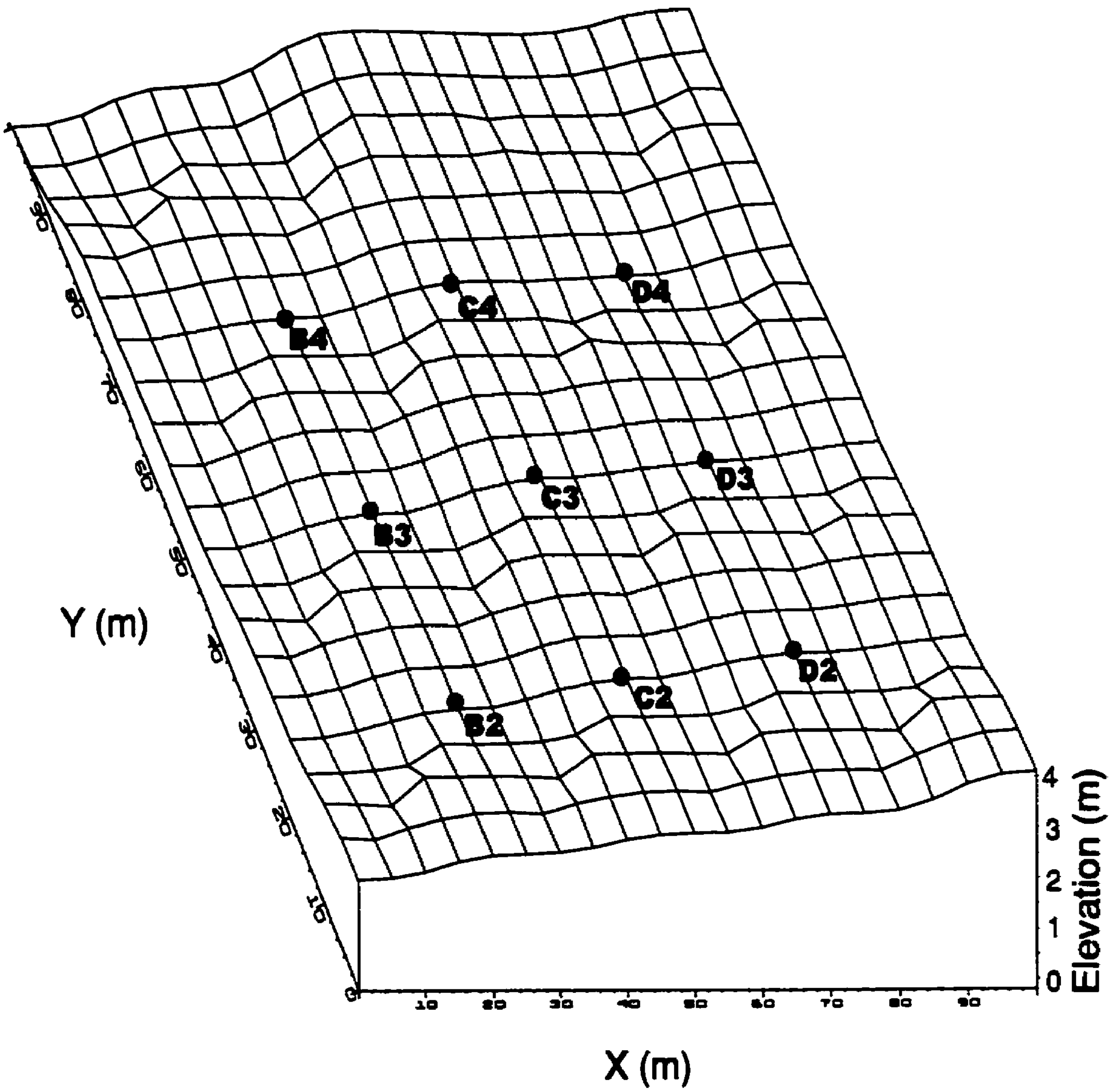


Figure 5.7 Digital elevation model of STF1 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

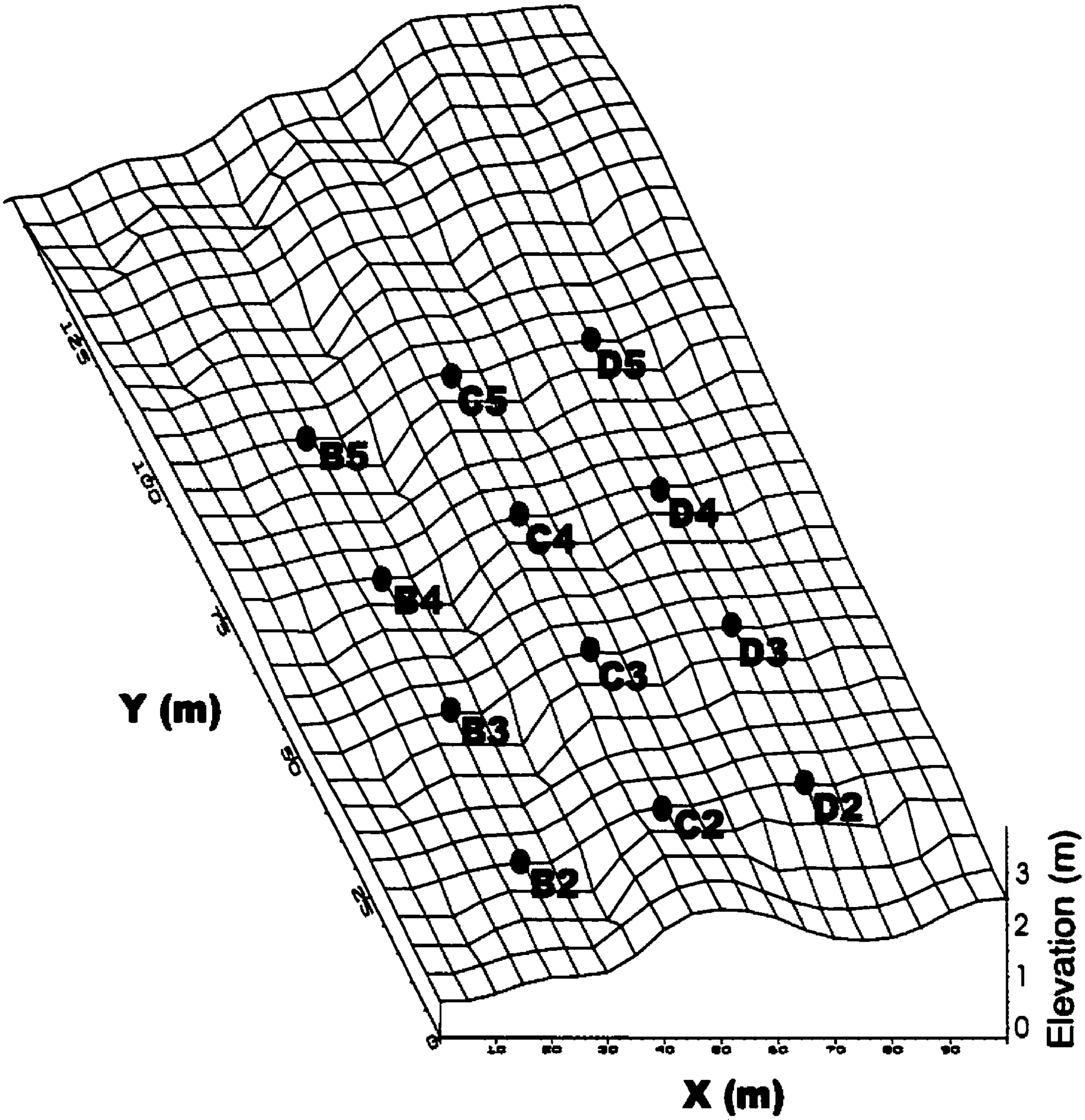


Figure 5.8 Digital elevation model of LTF1 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

ABF3 is on a mid slope position with 4 m relief over a 90 m distance. The site has the highest point at D2 and slopes to the lowest point at B4 (Fig 5.9). The A-horizon thickness varied little (from 5 to 6 cm) with few or very few concretions. Concretions were very few in the B horizon and only one sampling point (C2) has a Bx horizon. Most of the sampling points typically have B_1 or B_2tc. A few of the sampling points showed evidence of water logging; for example B2 and C3 had gleyed lowermost horizons.

Transect 3

The third transect is located in the heart of Kugri village away from the bush farm area and includes sites CF1, CF2 and CRF. The transect has an 8 m rise over a 400 m run. CF1 and CF2 are compound farms. These sites are continuously cropped and their fertility is maintained with household refuse and animal manure. CF1 belongs to the village chief's household. CRF is in a valley that runs through the village. It is cultivated to rice every year during the rainy season. CRF was added in the second field season because it was in an obvious position to receive sediment from the upper surface where CF1 and CF2 are located.

CF1 is on the summit/upper slope position and slopes from point D4 (highest) to B2 (lowest) (Fig 5.10). The A-horizon is a ploughed A-horizon and is designated as a Apc. Thickness of the Apc horizon varies from 5 to 7 cm with many to abundant concretions at all the sampling points (Appendix A1). Concretions are abundant throughout the profile of all sampling points, with Bx horizon occurring at lowermost horizons, commonly within 25-35 cm of the surface. At some points the Bx horizon occurred very close to the surface; for example, at sampling point C2, the Bx horizon occurred about 11 cm from the surface.

CF2 (Fig. 5.11) is in the midslope position of this transect. Similar to CF1, concretions are common in the Apc horizons of all the sampling sites; however, the sampling points on lower micro-elevations have thicker A-horizons than higher elevation points.

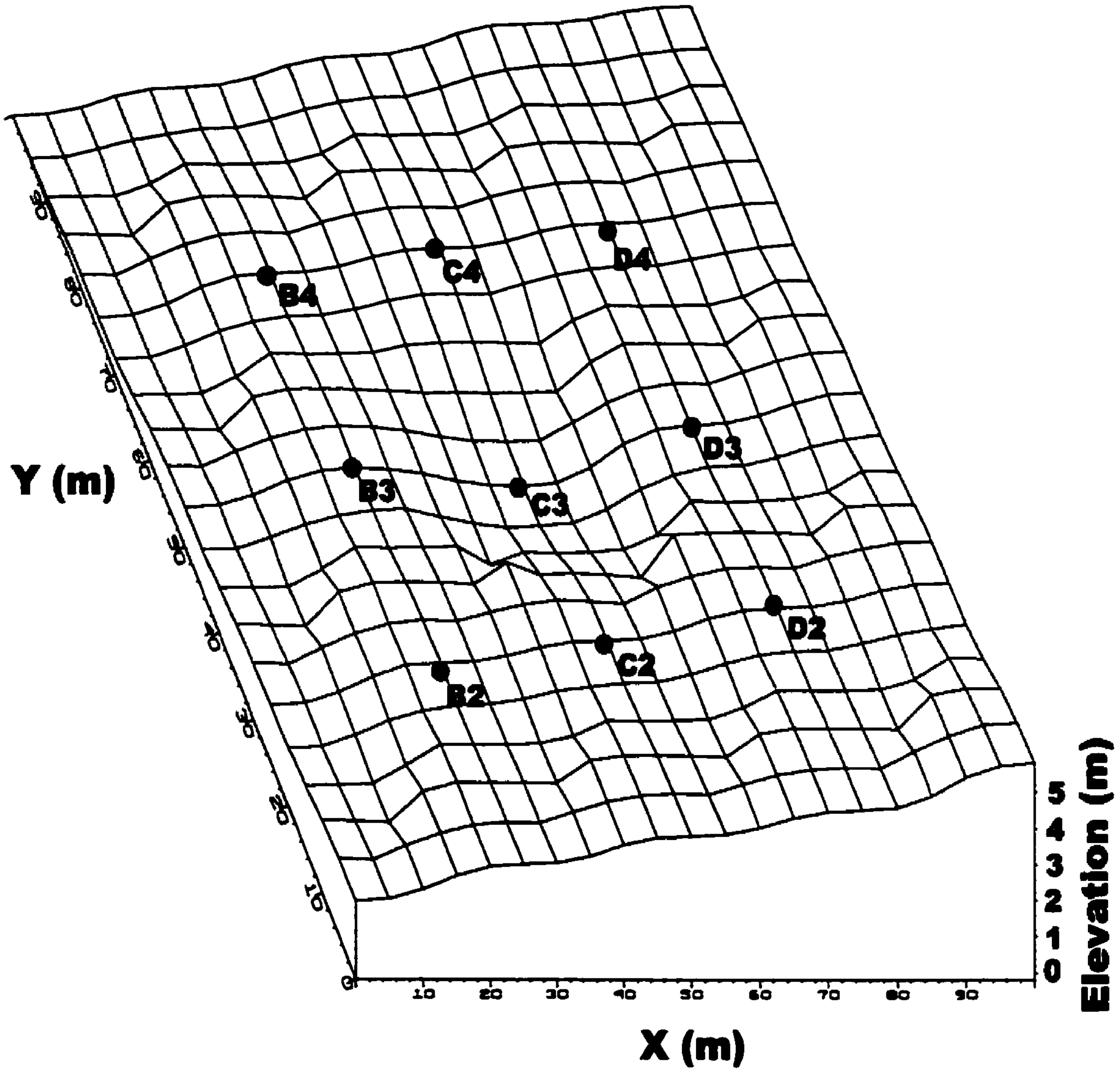


Figure 5.9 Digital elevation model of ABF3 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

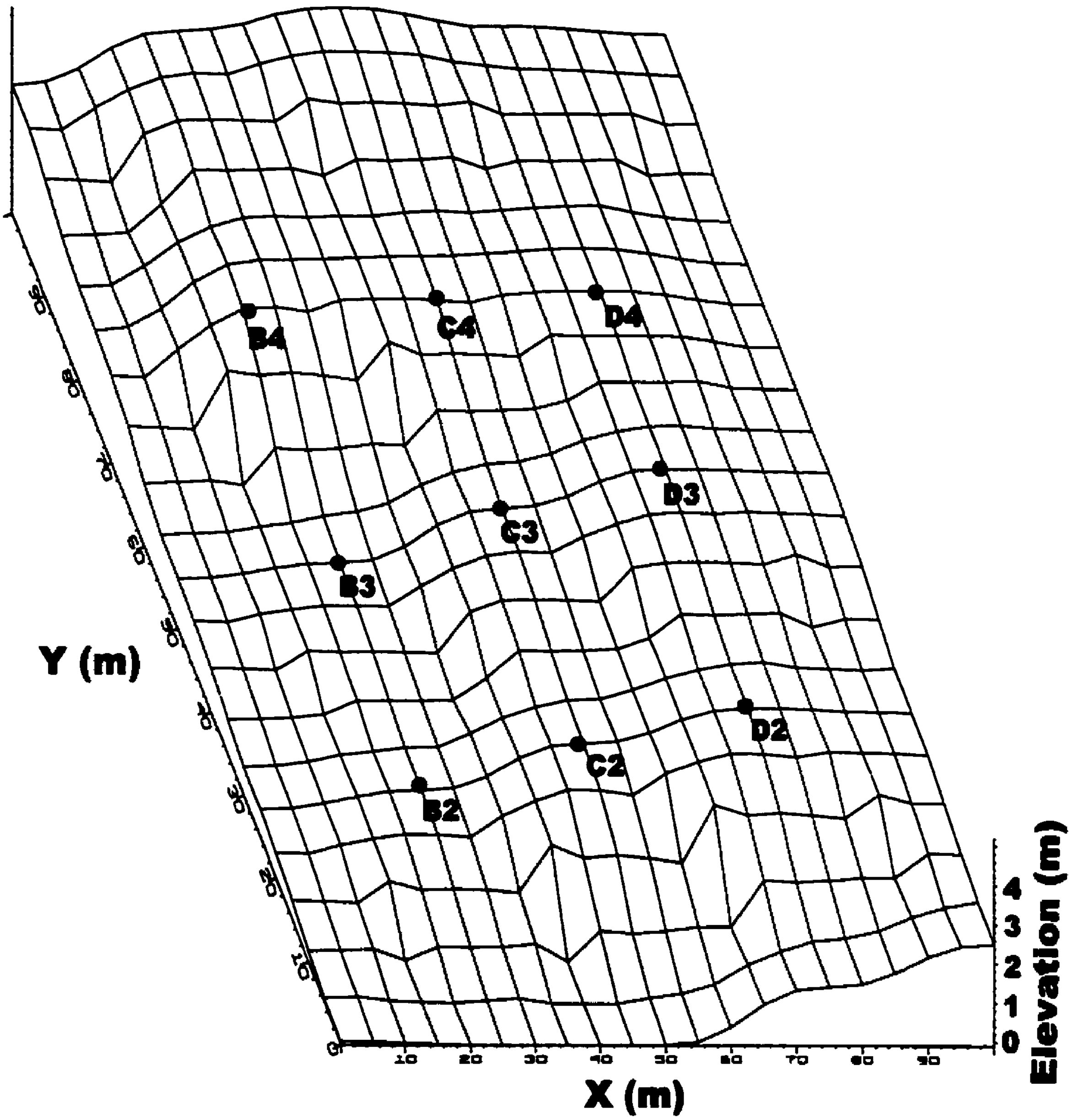


Figure 5.10 Digital elevation model of CF1 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

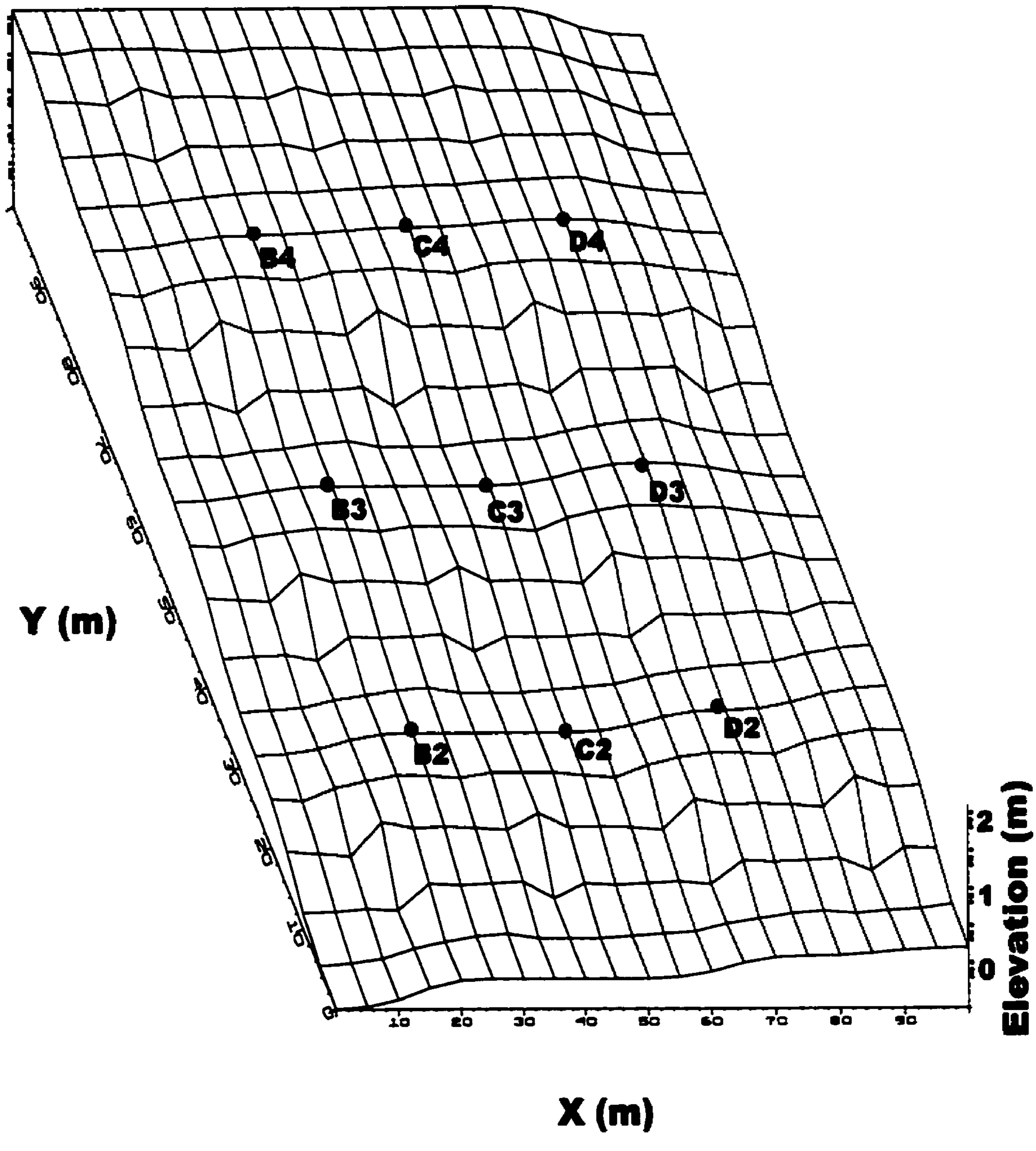


Figure 5.11 Digital elevation model of CF2 showing the micro-topography variations in the site. Soil pit locations referred to in text are shown on the surface. The view is from the southwest and the vertical exaggeration is 25X.

The texture of the upper horizons is loamy sand and the lowermost horizons are gleyed, especially at sampling points B3, B4, C4, and D3 (Fig. 5.11). Compared to CF1, this site did not have Bx horizons occurring within the depth of sampling. Only one sampling point (C2) had a Bx lowermost horizon, which occurred at 61 cm depth.

CRF is in the lowermost position on this transect. It is a near-level site in a broad concavity close to CF1. It is used for vegetable gardening in the dry season and rice farming in the rainy season. Generally the soil at this site is sandy loam to 30 cm depth and clayey at depth with soft and hard MnO concretions.

Transect 4

Sites STF2, STF3, and LTF2 are clustered along the fourth transect (Fig 5.2). This transect has a very gentle slope of 3 m rise over 400 m run with a "step" cut between STF2 and LTF2. STF2 is the lowermost point on the transect and is a short-term fallow field on a flood plain. It had previously been cultivated to rice. LTF2 has been fallowed for 20 years and STF3 for five years

Site STF2 is located in a concave lower-slope position at the edge of a low-lying wetland. There is a major gully about 50 m south of STF2, which appears to be a major water way in the area during the rainy season. The texture of the soil at this site is generally a silty fine sandy loam in the upper horizons with frequent quartz gravel and Fe concretions within 40 cm depth. There are very few concretions above 40 cm.

LTF2 and STF3 are in a mid- to upper slope position with several "hard-pan" exposures and hardened "laterites" at the surface. At most sampling points, the soils are very concretionary to the surface with concretionary boulders often at 10 to 30cm depth, and abundant concretions in the 0- to 10-cm layer.

Transect 5

ABF5, ABF6, and ABF7 are in the final transect. These sites are close to a prominent volcanic extrusion known as Kugri hill (Adu, 1969). This hill is the highest point in the study area. The hill forms its own catchment area and several major gullies begin at the base of the hill. These gullies coalesce to form a deep gully/stream that was dry at the time of sampling but which had ample evidence of fluvial sedimentation in the floodplain. There was considerable evidence of active rill erosion and deposition on the surface where the three sites were located. Although the three sites are located on a very different surface than the other four transects (and are not connected directly through surface flow) they were included because the land in the Kugri hill catchment is the most fertile of the bush farm areas. ABF5 and ABF6 are within the valley and have been continuously cultivated for several generations. At the time of sampling ABF7 was not yet seeded but remnants of the previous year's crops residue showed it was cropped to groundnuts.

The saprolite (i.e., deeply weathered bedrock) is very close to the surface at all three sites. ABF7 is located at a slightly higher elevation, and is separated from ABF5 and ABF6 by a dry (at the time of sampling) streambed that runs through the valley. The soil at this site is colluvial with a distinct stone line of concretions and quartz gravel overlying saprolite at 20 to 30 cm. This site did not seem to be affected by deposition or flow from Kugri hill and is probably more closely related to the soils of the other transects.

ABF5 and ABF6 are active deposition/erosion sites. There is considerable evidence of recent deposition of sediments at ABF5 and ABF6. ABF5 is sandier and has more concretions than ABF6. ABF6 is in a lower slope position. Some distinct sand layers within a finer, 5-cm thick depositional layer were observed after a day of rainfall in ABF6, which is a clear evidence of particle size separation. At these two sites also, the saprolite is commonly within 20 to 30 cm of the surface. Both sites had much browner A horizons than were common to the soil of the other transects.

5.3.2 Summary of pedogenetic and landscape relationships

Grouping of the study sites into discrete soil geomorphic units was difficult. The soils described at each site showed little correspondence to the conceptual series of the Varempere association shown in the soil survey report (Adu, 1969) and a considerable range in morphological properties occurred among sites that to occupied the same geomorphic surface.

Placement of the study sites (excluding the Kugri hill catchment sites) based on thier relative position along the land surface allows two broad distinctions to be made (Figure 5.3). Sites STF2, CRF, ABF2 and ABF4 occupy lower slope positions at the base of the long, gentle slopes characteristic of the region. Sites STF2 and CRF are in concave positions at the base of the slope and are seasonally flooded. CRF is currently used for wet season rice farming and STF2 was used for that purpose until very recently. Both of these sites have finer textured soil (especially at depth) than the remainder of the sites. Sites ABF2 and ABF4 occupy the lowest position of the overall slope complex but are still dominated by linear slopes (rather than concave slopes). Both of these sites have gleying features throughout the profile, but the texture and amount of concretions differ – ABF4 has a thick surficial sand cover, whereas ABF2 has higher concretions throughout the profile.

The remainder of the sites (excluding those in the Kugri catchment) occupy either mid- or upper slope positions and share most of the same features – reddish soil colours, concretions throughout the profile and the presence of mottling in a few of the profiles. They typically have abundant concretion and/or fragipan layers at some depth from the surface. The extreme occurrence of the massive concretionary layer is at sites LTF2 and STF3, where hardened plinthite occupied an appreciable fraction of the surface soil as either boulders or a continuous layer. No meaningful soil geomorphic differences could be made between these soils based on the survey methods used, and they are grouped together as upper slope soils for subsequent analysis.

The three sites in the Kugri hill catchment are distinct from the sites discussed above. Site ABF7 is outside of the area of active deposition in this catchment and is a classic colluvial soil with a distinct stoneline overlying saprolite. Sites ABF6 and ABF7 are in an active depositional landscape position and are similar in terms of colour and horizonation. Again the saprolite is close to the surface for both of these soils. These soils are also distinct from the other sites insofar as they are continuously cultivated bush farms.

The major reference or benchmark site in this study is UC, which is located in the upper slope group discussed above. As discussed previously, there is a need to establish a basic similarity among sites before the results for soil properties from a reference site can be used as a baseline to evaluate changes in soil quality. Based on the results of the geomorphic context of the sites, the properties of UC can be used as a baseline for the other upper slope sites, but cannot be reliably used for the lower slope soils and those of the Kugri hill catchment.

The limitations to the use of UC (and LTF1) as a reference site for ^{137}Cs concentrations are not as severe. One of the assumptions of the ^{137}Cs technique is that the ^{137}Cs concentrations in a local area reflect precipitation inputs, rather than soil conditions. This assumption has certainly been the source of considerable discussion over the years but the assumption that the reference levels at UC and LTF2 can be extrapolated to the local area is consistent with the literature on the use of ^{137}Cs.

5.3.3 Soil colour

Soil colour varies with slope and drainage conditions. From the well drained upland soils (UC, LTF1, ABF1, STF1, and CF1) to the very poorly drained valley bottom soil (STF2, CRF), colour changed from bright reddish brown to bluish grey. The red colour indicates good drainage and the type of iron in the soil. The reddish brown or brownish red colours denote a non-hydrated Fe oxide in the soil, hematite (Fe_2O_3) (Ahn, 1974). In the poorly drained midslopes and lower slopes (ABF2, ABF4) soils are brown or yellow in colour. This is due to the presence of hydrated iron oxides mainly goethite and limonite. Where drainage is very poor and the water table fluctuates and all or part of the profile is waterlogged, reduction of iron and other compounds becomes the predominant process. The colours typical of reduction conditions are bluish grey, greenish grey and natural grey as was observed in CRF. Where waterlogging is intermittent or seasonal, instead of a uniform grey colour, mottles are produced as was observed in sites ABF2, ABF4, CF2, and STF2.

5.3.4 Iron oxide content of soils

Oxides of Fe and Al and some highly resistant minerals, either inherited or transformed from the parent rock, are the most common minerals found in highly weathered soils of the tropics (Schwertmann and Herbillon, 1992). Iron oxides can occur in the soils as fine grained, poorly crystalline or amorphous materials which become crystalline at high temperatures (Sherman et al., 1964). In the amorphous form, they influence soil properties such as surface charge, specific surface area and aggregation. An important influence of Fe oxides in these soils is the increased P and micronutrient sorption capacity (Abekoe, 1996; Tiessen et al., 1993). Fe oxides also influence magnetic susceptibility of soils (Mullins, 1977; Vadyunina and Babanin, 1972) a property that is used to trace sediment source and redistribution as well as to assess pedogenesis.

Dithionite-citrate-bicarbonate (DCB) extractable-Fe (Fe_d) and oxalate extractable-Fe (Fe_o) were measured to determine the relative amounts of the amorphous and crystalline Fe-oxide (Table 5.2). Fe_d was greater than Fe_o for all sites. The higher Fe_d at all sites in this study is an indication of the predominance of crystalline Fe-oxide. The high temperature and the prolonged dry season prevalent in the savanna zone of West Africa may be responsible for the higher amount of crystalline Fe fractions in these soils (Juo et al., 1974). Drying at elevated temperatures causes the poorly crystalline Fe to dehydrate and develop greater crystallinity.

The soil fines at CF1 had the highest Fe_d content. This is consistent with the high amount of concretions in the bulk soil. The main constituent of concretions or nodules is Fe oxide with variable amounts of substituted Al within the structure (Sherman and Kanehiro, 1954; Tiessen et al., 1991b). Bulk soil with a high amount of concretions is therefore expected to have high crystalline Fe oxide contents.

Characteristically, concretions or nodules contain substantially higher Fe oxide than the surrounding soil (Taylor and Schwertmann, 1974). In the soils from all the sites, the concretion Fe_d was about two to ten times greater than the Fe_d of the soil fine and much greater than the corresponding Fe_o (detailed data not shown). The mean Fe_d of the concretions was 83.2 g kg^{-1} and an average value of 7.6 g kg^{-1} measured in the soil fines. However, Fe_o of the concretion was lower than that of the soil fines. The highest value of Fe_o for the soil fines was 3.4 g kg^{-1} and that of the concretions was 1.3 g kg^{-1}. Oganuga and Lee (1973) reported similar findings from soils of southwestern Nigeria.

The greater amount of Fe_d compared to the Fe_o in the concretions is also attributed to the crystallinity of iron oxide in these concretions, which is consistent with reports that the main component of ferruginous nodules are goethite and hematite (Tiessen et al., 1991b). In addition to the concretions, other factors such as the drainage condition as well as soil temperature could influence transformation of Fe oxides in soils. Aerobic conditions and high temperatures associated with burning encourage transformation of amorphous Fe to crystalline Fe.

The Feo/Fed ratios ranged from 0.03 to 0.42, which is consistent with values reported for different parts of the tropics (Juo et al., 1974; Ogunsola et al., 1989; Agbenin, 1992; and Abekoe, 1996). The ratio of Fe_o to Fe_d is an important measure that can be used to characterize a number of important properties of the soil. According to McKeague and Day (1966) the Fe ratio can be used as a relative measure of crystallinity or aging of the free Fe-oxides and therefore soil development. Younger soils have higher Fe_o/Fe_d ratios than older soils. The Fe_o/Fe_d ratio is normally less than unity, and approaches zero in older tropical soils (Alexander, 1974). Alexander (1974) classified soils with Fe ratio above 0.35 as young soils and below 0.2 as old soils. They can also be used to characterize drainage conditions of the soil. Stonehouse and St.Arnaud (1971) used the Fe ratio to distinguish between well drained and poorly drained soils; well-drained soils had values less than 0.35, and poorly drained soils had values greater than 0.35.

Table 5.2. Dithionite-extractable Fe (Fe_d), oxalate-extractable Fe (Fe_o) (g kg^{-1}) and Fe ratio (Fe_o/Fe_d). Values shown are mean and standard deviation (in bracket)

	Fe-content (g/kg)					
	0-10 cm			10-20 cm		
Site	Fe_d	Fe_o	Fe_o/Fe_d	Fe_d	Fe_o	Fe_o/Fe_d
			Varempere association- upper/mid slope			
UC	7.8 (2.2)	0.5 (0.1)	0.07	8.7 (2.9)	0.5 (0.1)	0.06
LTF1	10.8 (1.7)	0.9 (0.1)	0.09	12.3 (2.2)	1.0 (0.3)	0.09
STF1	5.3 (1.0)	0.4 (0.1)	0.08	7.1 (2.2)	0.5 (0.1)	0.07
ABF1	9.0 (2.2)	0.5 (0.1)	0.06	8.9 (1.6)	0.5 (0.1)	0.06
CF1	32.5 (10.5)	0.7 (0.1)	0.03	55.8 (32.1)	0.7 (0.1)	0.02
LTF2	7.6 (2.6)	0.8 (0.5)	0.11	7.7 (3.3)	0.7 (0.5)	0.11
STF3	5.4 ((1.6)	0.4 (0.1)	0.08	6.9 (2.3)	0.4 (0.1)	0.06
CF2	6.1 (0.5)	0.5 (0.3)	0.08	6.8 (1.1)	0.5 (0.1)	0.08
ABF3	6.8 (0.8)	0.9 (0.4)	0.14	6.2 (1.1)	0.9 (0.3)	0.16
			Varempere association- lower slope			
ABF2	3.0 (1.3)	0.7 (0.3)	0.25	3.3 (1.5)	0.5 (0.1)	0.17
ABF4	2.6 (0.4)	0.6 (0.2)	0.24	2.4 (0.4)	0.7 (0.3)	0.27
STF2	8.3 (2.4)	3.4 (2.2)	0.42	10.8 (4.1)	2.5 (1.1)	0.25
CRF	5.7 (1.0)	1.9 (0.6)	0.35	6.3 (1.5)	2.0 (0.3)	0.32
			Kugri-hill catchment			
ABF5	3.2 (0.5)	1.0 (0.4)	0.32	3.9 (1.0)	0.8 (0.2)	0.22
ABF6	4.7 (0.8)	1.1 (0.4)	0.25	4.7 (0.7)	1.1 (0.3)	0.22
ABF7	3.2 (0.6)	0.5 (0.2)	0.15	3.7 (0.7)	0.5 (0.2)	0.13

The results of this study supported the usefulness of the Fe ratio in soil classification. The sites (UC, LTF1, STF1, ABF1, CF1, LTF2, ABF3, and CF2) on the upper slope position of the Varempere association have Fe ratios less than 0.2. The low Fe ratio measured on the upper slope positions is an indication of a preponderance of crystalline Fe-oxide is consistent with reports that the upper slope positions are occupied by older, well-drained soils (Section 2.2.2.1).

The sites on lower slope positions (ABF2, ABF4, STF2, and CRF) had higher Fe ratio values, which is consistent with their drainage condition. STF2 and CRF, which have the highest values, occur in slope positions that experience seasonal water logging and are therefore used for rice cultivation. ABF4 and ABF2 are also poorly drained despite the sandy nature of the soils as was indicated by the mottles within the lower horizons of the soil profiles. In these lower slope positions, the anaerobic conditions and or organic matter accumulations slow down the process of Fe-oxide transformations causing the Fe-oxides to remain in readily extractable forms; hence the high Fe_o/Fe_d ratio (Schwertmann, 1966; Blume and Schwertmann, 1969; Fine and Singer, 1989; Moore, 1973). The high Fe_o in these lower slope sites may also a reflect their younger age because Fe_o provides a measure of accumulation of amorphous products of recent weathering. This is probably the explanation for the relatively high Fe ratio recorded for ABF5 and ABF6. These two sites are located in the valley and the soils are therefore young.

5.3.5. Magnetic susceptibility

The magnetic susceptibility results followed similar trends to the Fe oxide distribution (Table 5.3). Upper slope soils, with high amounts of concretions and Fe oxide, had higher values than middle and lower slopes. This trend is to be expected because there is a direct relationship between magnetic susceptibility and Fe oxide content. The degree of magnetic activity exhibited by a soil sample depends on the magnetic properties of its constituents. Constituents of importance are ferrimagnetic minerals such as magnetite and maghemite (Oades, 1963).

The frequency dependence of magnetic susceptibility was closely related to the low frequency magnetic susceptibility and decreased from upper to lower slope positions. The frequency dependence of the magnetic susceptibility reflects the concentration of very fine ferrimagnetics, which are of pedogenic origin (Fine et al., 1989). Fine et al. (1992) found a significant positive relationship between magnetic susceptibility and Fe_d content, which was assumed to be a measure of pedogenesis.

Old soils found on the upper slope positions have high amounts of ferrimagnetic materials that are concentrated in concretions and nodules. To determine the level of magnetic enhancement of the concretion a selected quantity of concretions, stratified by site and size, were ground and their magnetic susceptibility measured. The degree of magnetic enhancement appeared to be related to the size of concretions. In the uncultivated site, the smaller grained concretions were more magnetically enhanced than the larger rough shaped ones (detailed data not shown). The fine concretions at this site had magnetic susceptibility values above $200x10^{-8}\ m^3\ kg^{-1}$, and the large coarse concretions had values about $30x10^{-8}\ m^3\ kg^{-1}$, while the moderately coarse ones measured about $50x10^{-8}m^3kg^{-1}$. At sites (ABF1 and STF1) where large coarse concretions predominate, the average magnetic susceptibility for the concretions was about $27x10^{-8}\ m^3\ kg^{-1}$.

According to Tite and Mullins (1971) burning of vegetation and high organic matter are important in transforming magnetically weak material into ferrimagnetics such as maghemite. The combustion of organic compounds produces a reducing atmosphere which leads to the transformation of weakly magnetic iron oxides (weathering products) (Fine et al., 1989). Goethite and hematite are converted to magnetite, which may in turn oxidize to maghemite when air enters the soil upon cooling (Mutsusaka and Sherman, 1960; Mullins, 1977). Organic matter and its decomposition products are highly effective in mobilizing iron, regardless of soil type.

Table 5.3. Low frequency magnetic susceptibility (X_{lf}) and absolute frequency dependent magnetic susceptibility (X_{afd}). Values shown are mean and standard deviation (in brackets).

	X_{lf} ($x10^{-8}m^3kg^{-1}$)		X_{afd} ($x10^{-8}m^3kg^{-1}$)	
Site	**0-10 cm**	**10-20cm**	**0-10 cm**	**10-20 cm**
	Varempere association- upper/mid slope			
UC	60.3 (11.4)	60.0 (10.4)	6.3 (1.1)	6.4 (1.2)
LTF1	114.4 (13.9)	114.6 (20.5)	10.0 (1.8)	9.9 (1.2)
STF1	58.2 (5.3)	54.7 (6.9)	5.6 (0.6)	5.8 (0.9)
ABF1	80.1 (19.6)	61.5 (12.4)	7.6 (2.0)	6.1 (1.5)
CF1	196.2 (22.7)	212.4 (38.8)	13.3 (1.7)	15.2 (3.5)
LTF2	61.7 (34.1)	61.7 (21.1)	5.1 (2.6)	4.0 (1.6)
STF3	39.7 (4.7)	39.5 (4.2)	3.5 (0.5)	3.5 (0.6)
CF2	76.3 (3.8)	85.4 (11.2)	5.5 (1.0)	7.2 (1.2)
ABF3	41.9 (21.8)	32.8 (24.0)	4.4 (2.3)	3.3 (2.7)
	Varempere association- lower slope			
ABF2	11.1 (12.6)	8.6 (15.3)	1.0 (1.3)	0.8 (1.8)
ABF4	7.7 (4.2)	2.7 (0.8)	0.6 (0.4)	0.2 (0.1)
STF2	14.5 (4.6)	8.6 (3.0)	1.0 (0.3)	0.4 (0.2)
CRF	10.5 (1.7)	12.0 (1.1)	0.4 (0.2)	0.3 (0.1)
	Kugri hill catchment			
ABF5	12.7 (2.5)	10.5 (4.6)	0.8 (0.3)	0.5 (0.3)
ABF6	23.3 (8.2)	17.7 (9.3)	1.3 (0.7)	0.9 (0.8)
ABF7	23.3 (9.4)	21.0 (9.1)	2.1 (0.8)	2.0 (0.9)

Native site (UC), Active Bush Farm (ABF), short-term fallow (STF), long-term fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF).

The decomposition of organic matter may enhance magnetic susceptibility at the soil surface by releasing up to 3% of the total soil iron. High organic matter content and heterotrophic microorganisms near the surface may promote the formation of ferrimagnetic minerals. Thus in aerobic soils, the bulk of magnetic susceptibility is associated with the Ah or Ap horizons where the released ferrous iron can be reoxidized to its ferric form and resultant mineral species. The influence of extensive burning and organic matter additions on the magnetic enhancement of soils was apparent in site CF1. At CF1, the moderately coarse sized concretions similar in size to those found in UC (mentioned above) had values above $300*10^{-8}\ m^3\ kg^{-1}$. CF1 is a compound farm that receives high amounts of organic manure, household ashes and the frequency of burning is also high at this site.

Where the Fe_o/Fe_d ratios are more than 0.2 (i.e., indicative of reducing conditions), the X_{lf} values are all less than 40, and X_{afd} values are less than 4. Given the ease of magnetic susceptibility measurements, this is a useful finding that indicates that magnetic susceptibility can be used in combination with field descriptions to characterize drainage conditions of fields.

The magnetic susceptibility results do not indicate the occurrence of soil deposition in the lower slope sites. The surface soil increments of the upper slope sites clearly show considerably higher values for X_{lf} and X_{afd} than the four lower slope sites. If deposition of the magnetically enhanced sediment from the upper slope sites was occurring in the lower slope positions, we should find a layer of higher X_{lf} and X_{afd} sediment overlying the lower X_{lf} and X_{afd} surface soils in the lower slope positions (as found by de Jong et al., 1998). The absence of this material suggests that either little erosion of the upper slope soils is occurring or that the soil that is being eroded is not being deposited at the lower slope sites.

5.3.6 Concretion Content and Depth to Concretions

The concretions present in the soil are a major criterion used by local farmers to assess the quality of the soil (as discussed above in section 4.2.1.1). Their qualitative classes range from zigikuga (high concretion content soils where gravel content is greater than the fines) to lower-slope zigikoba soils with very low gravel contents. This latter class is regarded as the best soils by the local farmers.

The soils are commonly concretionary, with the amount and depth to concretions depending on slope position (Table 5.4 and Fig. 5.12). The soils from the upper slope sites of the Varempere association generally had high amounts of concretions. Concretion contents in excess of 40% occurred within 20 cm of the surface at sites STF1, LTF1, ABF1, CF1, STF3, and LTF2 (Fig. 5.12). At sites STF3 and LTF2, the high concretion content of the surface soils is further exacerbated by the presence of concretionary boulders and complete plinthite covers within the extent of the surveyed sites.

Cultivation exposes the concretions to the surface. The topsoil of the uncultivated site (UC) did not have as many concretions as the cultivated sites within the same landscape position. For example, CF1 has about 40% concretion by weight in the 0- to 10-cm layer and 58 % concretion in the 10- to 20-cm layer. This site is a compound farm that had been in continuous cultivation for generations. At the surface, the concretions are spherical in shape and less tightly packed, possibly as a result of selective removal of fines by erosion.

The lower slope soils of the Varempere association have low or non-existent concretion contents to at least a depth of 50 cm (Figure 5.12). The lack of concretions in these soils and their presence in the upper slope soils suggests that the landscape has experienced several cycles of erosion (Ollier, 1991) (Section 2.2.2.2) because concretions are expected to be formed in poorly drained conditions.

At site ABF7 in the Kugri hill catchment, the concretions and gravels are inter-mixed in a distinct colluvial stoneline rather than being distributed throughout the fine matrix such as the upper slope sites. At sites ABF5 and ABF6 the concretions and gravels occur dispersed throughout the loose soil matrix overlying the saprolite.

Table 5.4. Percentage concretions measured in the two sampling depths. Values are mean and standard deviation (shown in brackets).

Site	Concretion content (%)	
	0-10 cm	10-20 cm
	Varempere association-Upper/mid slope	
UC	7.4 (4.8)	22.1 (20.2)
LTF1	24.0 (8.1)	31.9 (9.8)
STF1	25.1 (15.0)	46.3 (17.9)
ABF1	44.0 (27.0)	58.2 (23.5)
CF1	40.9 (2.1)	58.4 (7.8)
LTF2	23.8 (29.7)	32.8 (31.8)
STF3	21.0 (18.9)	46.2 (22.6)
CF2	12.6 (2.1)	22.9 (8.5)
ABF3	6.6 (6.0)	17.2 (15.2)
	Varempere association-lower slope	
ABF2	1.7 (1.0)	4.0 (2.7)
ABF4	1.6 (0.9)	3.6 (2.6)
STF2	3.6 (4.1)	6.6 (4.8)
CRF	1.1 (0.5)	2.2 (1.5)
	Kugri hill catchment	
ABF5	16.2 (11.0)	22.2 (16.1)
ABF6	6.9 (5.3)	7.8 (6.8)
ABF7	8.2 (4.5)	21.8 (14.1)

Native site (UC), Active Bush Farm (ABF), short-term fallow (STF), long-term fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF).

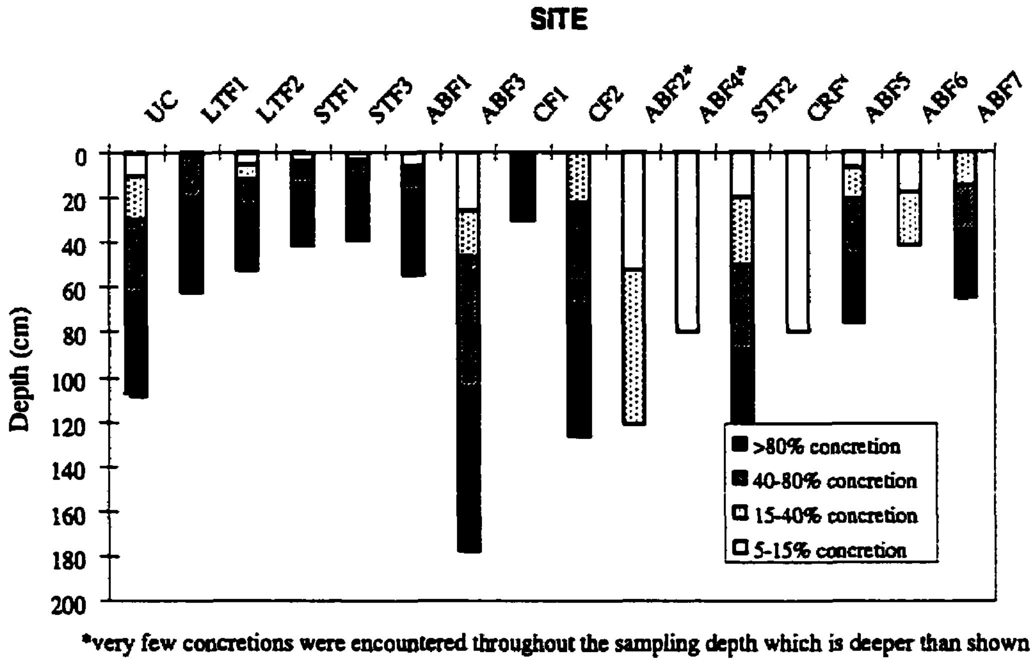


Figure 5.12: Depth distribution of concretion contents of the fully described central profiles at each site. The classification of concretion content was done according to FAO guidelines for soil description as follows: 1) common (5-15 % concretion); 2) many (15-40 %) concretion; 3) abundant (40-80 % concretion) and 4) dominant (more than 80% concretion by weight).

5.3.7 Relationship between Iron Content, Magnetic Susceptibility and Concretion Content

The results discussed above suggest that there is a relationship between concretions, Fe_d and magnetic susceptibility. These relationships were explored quantitatively using simple Pearson correlations among the mean values of each property at each site.

Overall the Fe_d content of the soils is strongly related to percent concretions and especially to the X_{lf} and X_{afd} values at the sites for both depths sampled (Table 5.5). The two magnetic susceptibility measurements are strongly correlated with each other, and are closely related to the iron mineralogy of the sites. The X_{lf} and X_{afd} values are higher in the magnetically enhanced upper slope soils, and are lowest in the less well drained lower slope positions. Hence magnetic susceptibility in these landscapes can be used as simple surrogate for the iron status of the soil, which is a dominant pedogenetic characteristic of these landscapes.

Generally, the higher the percent concretions in the two depths, the higher is the Fe_d content of the soil. As discussed earlier, this finding runs counter to the idea that concretions form in poorly drained conditions – the percent concretions had a significant inverse relationship with the iron ratio. As was noted earlier, where the Fe_o/Fe_d ratios are more than 0.2, the X_{lf} values are all less than $40*10^{-8}m^3kg^{-1}$ and X_{afd} values are less than $4*10^{-8}m^3kg^{-1}$. Thus magnetic susceptibility can be used to differentiate between well drained upland soils and soils in the lower slope position. Where drainage conditions are poor, magnetic susceptibility is less than $20*10^{-8}m^3kg^{-1}$.

Table 5.5. Pearson correlation coefficient and two-tailed significance test for relationships between inherent soil properties at the research sites. Correlations are assessed on the mean values for the properties at each site (N=16).

	Percent Concretions	Fe_d	Fe_o	Fe_o/Fe_d	*Xlf*	*Xafd*
	%	g kg^{-1}	g kg^{-1}		$*10^{-8}$ m^3 kg^{-1}	$*10^{-8}$ m^3 kg^{-1}
			0 to 10 cm			
Percent Concre-tions	1.000					
Fe_d	.62	1.000				
	.011					
Fe_o	-.37	.003	1.000			
	.162	.992				
Fe_o/Fe_d	-.66	NC[1]	NC	1.000		
	.005					
X_{lf}	.77	.90	-.29	-.70	1.000	
	.001	.000	.274	.002		
X_{afd}	.789	.80	-.36	-.79	.97	1.000
	.000	.000	.174	.000	.000	
			10 to 20 cm			
Percent Concre-tions	1.000					
Fe_d	.56	1.000	-	-		-
	.023					
Fe_o	-.47	-.00	1.000	-		-
	.067	.99				
Fe_o/Fe_d	-.77	NC	NC	1.000		-
	.000					
X_{lf}	.69	.87	-.28	-.68	1.000	-
	.003	.000	.291	.004		
X_{afd}	.74	.79	-.36	-.77	.98	1.000
	.001	.000	.170	.001	.000	

1: Correlations are not shown between the iron ratio and Fed or Feo because the iron ratio is derived from these two properties

The correlation of these two properties again indicates the complex nature of soil and landscape formation in this region.

5.3.8 Particle size distribution and bulk density

The particle size distribution showed that the soils are sandy (Table 5.6). Mean value for sand content was over 50% for all profiles except those of STF2, which were about 35%. Mean silt content varied between 10% to 40% while mean clay content is between 3%-25%.

The generally high sand content is typical of many soils in this region. The underlying rock is granitic in nature (Adu, 1969). Granites produce very sandy soils upon weathering. There were clay films in some subsurface horizons, which may be an indication of clay illuviation. These small increases in clay may compound problems of hard pan that are common in subsoil in the region and may inhibit root development, thus preventing crops from withstanding even moderate drought conditions.

The soils from STF2, ABF5, ABF6 and CRF have higher clay content compared to the other sites. This trend is again related to the position of these sites within the landscape. Both STF2 and CRF are located in lower slope concavities and ABF5 and ABF6 are in the Kugri hill catchment. ABF2, ABF3 and CF2 have very low clay contents and are situated in a mid-slope position where erosion is probably removing fine sized particles selectively and leaving the coarse lag behind. This is typical of the long, gently sloped landscapes in the tropics (Ahn, 1974).

Generally, the bulk density values are high (Table 5.7). This is related to the sandy nature of the soils and the low organic carbon content of the soil. Coarse textured soils have low porosity in spite of a large average pore size. Conversely, the total pore volume of fine-textured soils tends to be large and the bulk density values correspondingly low. STF2, which had the highest clay content, had the lowest value for bulk density (1.3 g cm^{-3}) whilst CF2 and ABF4, both of which had very high percentage of sand fraction, had the highest values (1.7 g cm^{-3}).

Table 5.6. Particle size distribution of surface 0- to 20-cm depth of the soils. Values shown are mean and standard deviation (in brackets).

Site[1]	Particle size distribution (%)					
	0-10 cm			10-20cm		
	Sand	Clay	Silt	Sand	Clay	Silt
			Varempere association-Upper/mid slope			
UC	69 (6)	12 (4)	19 (2)	68 (7)	15 (6)	17 (1)
LTF1	75 (5)	8 (2)	17 (4)	76 (4)	10 (2)	14 (3)
STF1	77 (4)	7 (2)	16 (2)	75 (7)	11 (4)	15 (2)
ABF1	75 (8)	10 (3)	15 (5)	76 (9)	12 (4)	12 (5)
CF1	84 (3)	5 (1)	10 (3)	81 (4)	10 (2)	9 (1)
LTF2	75 (8)	6 (2)	19 (6)	71 (5)	9 (3)	20 (7)
STF3	77 (3)	5 (1)	18 (3)	72 (5)	8 (2)	20 (5)
CF2	85 (3)	3 (1)	12 (3)	80 (3)	6 (1)	14 (4)
ABF3	81 (3)	7 (2)	13 (1)	80 (2)	10 (2)	10 (1)
			Varempere association-lower slope			
ABF2	74 (8)	6 (1)	19 (7)	77 (4)	7 (2)	16 (4)
ABF4	79 (5)	5 (1)	16 (5)	78 (3)	6 (1)	16 (3)
STF2	35 (17)	25 (7)	40 (12)	36 (11)	26 (10)	38 (17)
CRF	58 (11)	14 (3)	28 (11)	54 (7)	17 (2)	29 (8)
			Kugri hill catchment			
ABF5	77 (6)	10 (4)	13 (4)	70 (8)	14 (4)	16 (6)
ABF6	67 (12)	13 (5)	20 (8)	61 (13)	16 (5)	23 (9)
ABF7	81 (4)	5 (1)	13 (4)	79 (5)	8 (1)	14 (5)

[1]Native site (UC), Active Bush Farm (ABF), short-term Fallow (STF), long-term Fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF).

Table 5.7. Bulk density of the bulk soil and bulk density of soil fines (corrected for presence of concretions) and mass of soil fines per cm^3 bulk soil.

Site	Bulk density ($g\ cm^{-3}$, 0-10 cm depth)		
	Total[1]	Fine soil[2]	Fine soil[3]
	Varempere association-Upper/mid slope		
UC	1.57 (0.13)	1.52 (0.13)	1.45 (.012)
LTF1	1.67 (0.11)	1.51 (0.10)	1.27 (0.12)
STF1	1.70 (0.12)	1.53 (0.12)	1.24 (0.20)
ABF1	1.84 (0.16)	1.45 (0.18)	1.00 (0.42)
CF1	1.79 (0.08)	1.50 (0.10)	1.06 (0.07)
LTF2	1.71 (0.13)	1.50 (0.22)	1.28 (0.46)
STF3	1.74 (0.08)	1.58 (0.16)	1.37 (0.31)
CF2	1.71 (0.11)	1.66 (0.13)	1.52 (0.12)
ABF3	1.55 (0.09)	1.51 (0.09)	1.45 (0.14)
	Varempere association-lower slope		
ABF2	1.62 (0.08)	1.61 (0.08)	1.60 (0.07)
ABF4	1.72 (0.07)	1.71 (0.07)	1.69 (0.07)
STF2	1.31 (0.13)	1.29 (0.12)	1.26 (0.11)
CRF	1.64 (0.17)	1.64 (0.17)	1.63 (0.17)
	Kugri hill catchment		
ABF5	1.49 (0.14)	1.38 (0.13)	1.24 (0.15)
ABF6	1.45 (0.16)	1.41 (0.59)	1.35 (0.15)
ABF7	1.58 (0.13)	1.53 (0.15)	1.46 (0.17)

[1] Total mass/Total volume, [2] Mass of soil fine/Volume of soil fine, [3] Mass of fine/Total volume

Apart from texture, organic matter also affects the bulk density. Organic matter contributes to lower bulk density by encouraging higher porosity through soil aggregation or by reducing the average density of the soil particles. The effect of organic matter could be the explanation for the lower bulk density value of CF1 despite the high sand and concretion content. CF1 had relatively higher SOC than CF2, which is reflected in the relatively lower bulk density value recorded for CF1. CF1 was a compound farm that belongs to the chief of the village and his family. Comparatively, this family has access to more organic manure for the farm because of the larger number of livestock owned by the household.

Concretions increase the bulk density of soils in the same way as coarse-sized particles and rock fragments without necessarily increasing the associated fine earth's bulk density. For the interpretation of the behaviour of a soil with very coarse sized particles such as concretion and rock fragments, it is important to distinguish between total bulk density of the soil and the bulk density of the fine earth (Poesen and Lavee, 1994).

According to Poesen and Lavee (1994), as coarse fragment content increases, total bulk density increases to reach a maximum beyond which it decreases. Contrary to what was observed in total bulk density, fine earth density decreases linearly with increasing coarse fragment content.

The difference between the total bulk density and the fine soil bulk density values obtained by correcting for concretions confirmed the above observation. Total bulk density values were greater than fine earth bulk density in all the sites, especially for CF1, ABF1, and STF1. A number of explanations can be offered for this negative relationship. Large sized particles introduce voids, which reduce the fine earth bulk density. Also, decaying organic matter, fertilizer, and rain water tend to be concentrated into smaller volume of fine earth, decreasing mass of fine earth and thus, leading to a reduction in the fine earth bulk density (Childs and Flint, 1990).

5.3.9 Spatial variability of the inherent properties within fields

Landscape-scale research is often subject to external influences that the researcher may not be able to accommodate with a particular sampling plan. One important external influence is the spatial variability in soil properties within each research site. Spatial variability within soil properties can be divided into two categories: random variability and systematic variability. Random variability is unpredictable and the mechanisms that influence variability have either no spatial component or the spatial component is not well understood. Systematic variability on the other hand, is predictable if the pedogenetic pathways at the sites (which are its major control) are well understood (Hall and Olsen, 1991). By understanding the effect that landscape positions have on the soil development, the researcher is able to select research sites such that variability due to landscape can be easily accounted for, especially with macro-scale variability. Systematic variables that occur over relatively short distances (micro-scale) are, however, not easy to control at farm level. Landscape-scale research, therefore, requires an assessment of spatial variability within field.

Particle size distribution and bulk density were the least variable properties varying little among and within sites. The coefficients of variation recorded for these properties are much lower than what was reported for most temperate soil. For temperate soils, Warrick and Nielsen (1980) reported CV of 28% for sand, 32% for silt and 36% for clay as acceptable limits of variation within a study field. Lal (1985) indicated that limited variability is commonly observed in surface soils of the semi-arid tropics because of the highly weathered nature of the soils of the region.

Percentage concretions, iron oxide content, and magnetic susceptibility were the most highly variable properties (Table 5.8). Concretions are of pedogenic origin. They occur at depth and the degree of exposure is related to removal of surface soil. However, there are strong indications from the profile descriptions that they do not occur at a consistent depth under a uniform thickness of soil in most sites. Because of the irregular nature of their occurrence, there is variability in the rate of exposure.

Table 5.8. Coefficient of variation of inherent soil properties.

Site	Coefficient of Variation (%) Fine soil Bulk density	Sand	Clay	Silt
	Varempere association-Upper/mid slope			
UC	8	9	33	10
LTF1	7	7	25	23
STF1	7	5	27	12
ABF1	9	11	3	33
CF1	4	4	20	30
LTF2	8	11	33	32
STF3	5	4	8	17
CF2	6	3	23	25
ABF3	6	4	29	8
	Varempere association-lower slope			
ABF2	5	11	17	37
ABF4	4	6	20	31
STF2	10	46	28	30
CRF	10	19	21	39
	Kugri hill catchment			
ABF5	9	8	40	31
ABF6	11	18	38	40
ABF7	8	5	16	31

Table 5.8 cont. Coefficient of variation of inherent soil properties.

Site	Coefficient of Variation (%) Percent concretions	Fe_d	Fe_o	Magnetic susceptibility
	Varempere association-Upper/mid slope			
UC	65	28	20	19
LTF1	34	16	11	12
STF1	60	19	12	9
ABF1	61	24	20	25
CF1	5	32	14	12
LTF2	125	34	52	55
STF3	90	30	25	12
CF2	17	8	60	5
ABF3	91	12	44	52
	Varempere association-lower slope			
ABF2	59	43	43	113
ABF4	56	15	33	54
STF2	88	29	65	32
CRF	45	17	32	16
	Kugri hill catchment			
ABF5	68	16	40	20
ABF6	77	17	36	35
ABF7	59	19	40	40

For example, CF1 was in a position of the landscape where high amounts of concretions occur with homogenous distribution. LTF2 and STF3, on the other hand, had high concretions at a range of depths within field. These two sites were located close to a flood plain with iron pan exposed within various parts of the field. This micro-variability may have produced localized areas of erosion and areas of deposition within the field. There are many locations (micro depressions) where "concentration flow" may occur during the high magnitude runoff events associated with this region.

Over all, the highest CV (ranked by individual properties) was observed in the following sites: ABF1, ABF5, ABF6, LTF2 and STF3. ABF1 had many anthills that produced a highly variable micro-relief of the site (DEM Fig. 5.6). ABF5 and ABF6 are located in the valley being fed by Kugri hill, as such, they are actively undergoing erosion and deposition receiving as was evidenced by the particle size separation discussed earlier. The high variability in LTF2 and STF3 is related the presence of concretionary boulders and to the localized areas of exposed iron pan within various parts of these fields.

5.3.10 Summary of the Inherent Properties

The sixteen study sites were placed in three broad groups based on the inherent properties. An overall relationship exists at the study landscape between inherent soil properties and slope position. The three groups that emerged from the previous analysis are the upper slope sites, lower slope sites and the Kugri hill catchment sites. The upper and lower slope sites belong to the Varempere soil association, whereas the Kugri catchment sites (transect 5) belong to a different association.

UC, ABF1, STF1, LTF1, CF1, ABF3, CF2, LTF2 and STF3 were located on the upper slope positions of the Varempere soil association. ABF2 and ABF4, STF2 and CRF were located in lower slope positions of the same association. ABF7, ABF6 and ABF5 are entirely different from the remaining sites. They are formed in local alluviums derived from the Kugri catchment.

The upper slope sites are dominated by thinner, concretionary soils. The amount of concretions measured in the soils from these sites was high. The lower slopes are generally occupied by relatively thick soils with limited concretions. In terms of moisture status, the upper landscape positions are subject to drier conditions than the lower landscape positions. Topography induces water redistribution through its effect on drainage, surface and subsurface water flow, and lateral flow of shallow ground water that recharges in localized depressions. The upper slopes are well drained whereas the middle and lower slopes are poorly drained. This is consistent with the colour of soils in the different groups. Colour of the soils at the upper slope sites were bright reddish brown indicating the presence of hydrated Fe oxide due to the good drainage conditions of the soil. The lower slope soils were bluish grey indicating reducing conditions.

The upper slope sites had higher amount of dithionite-extractable Fe compared to the sites on the mid/lower slope positions. High measures of dithionite–extractable Fe are a reflection of high amounts of crystalline Fe. Feo on the other hand, was lower for the upper slope sites than the lower slope sites, albeit with a smaller range. Also, there was a clear relationship between the landscape and the Feo/Fed ratio. The values for the upper slope sites were less than 0.2 while the lower slope sites were more than 0.2. The magnetic susceptibility values were also landscape related. Upper slope sites were dominated by soils with high magnetic susceptibility. Lower slope soils had lower magnetic susceptibilities.

The soils from the Kugri hill catchment differ from those of the other research sites. Sites ABF5 and ABF6 are located in an active colluvial surface while ABF7 is located on the flank of the bed. The saprolite at these sites is quite close to the surface at about 20 to 30 cm from the surface. ABF7 for example, has a stone line overlying saprolite, while ABF5 and ABF6 show active deposition and erosion features. In the succeeding chapters all data are presented according to these groupings.

6. SOIL REDISTRIBUTION AND DYNAMIC SOIL PROPERTIES

6.1. Soil Redistribution

Soil redistribution is a major determinant of the magnitude and direction of changes in soil quality. The soil loss process removes surface soil from the point where the erosion is occurring, while the deposition component can bury the surface soil at the point of deposition or the soil leave the site and pollute rivers. The erosion process is a primary control of soil quality because each time soil is lost part of the organically rich surface soil is lost and the B or C horizon materials are incorporated into the plough layer (Pennock, 1997). This is especially important for soils with less productive B-horizons as frequently encountered in the semi-arid tropics. In these environments, the study of soil erosion is very important to soil quality evaluation. Hence, the study of erosion using the ^{137}Cs technique was an important component of this study.

6.1.1. The local ^{137}Cs reference inventory

The use of ^{137}Cs technique requires a local reference point for estimating the rates of erosion and deposition. The reference fallout inventory is typically established from long-term uncultivated sites. The use of an uncultivated site as a reference assumes a locally uniform fallout distribution (Walling and Quine, 1995). Because this assumption is difficult to test retrospectively (Walling and Quine, 1995), the reference sites selected must be very close to study sites. Identification of suitable reference sites is often problematic especially in intensively cultivated regions such as northeastern Ghana. Two appropriate locations were identified and sampled. The first reference site (UC) is an uncultivated savanna woodland and the second reference site (LTF1) has been in fallow for about 50 years and has degraded savanna woodland vegetation. Analysis of these samples provided an estimate of the local reference inventory (Fig. 6.1 a & b).

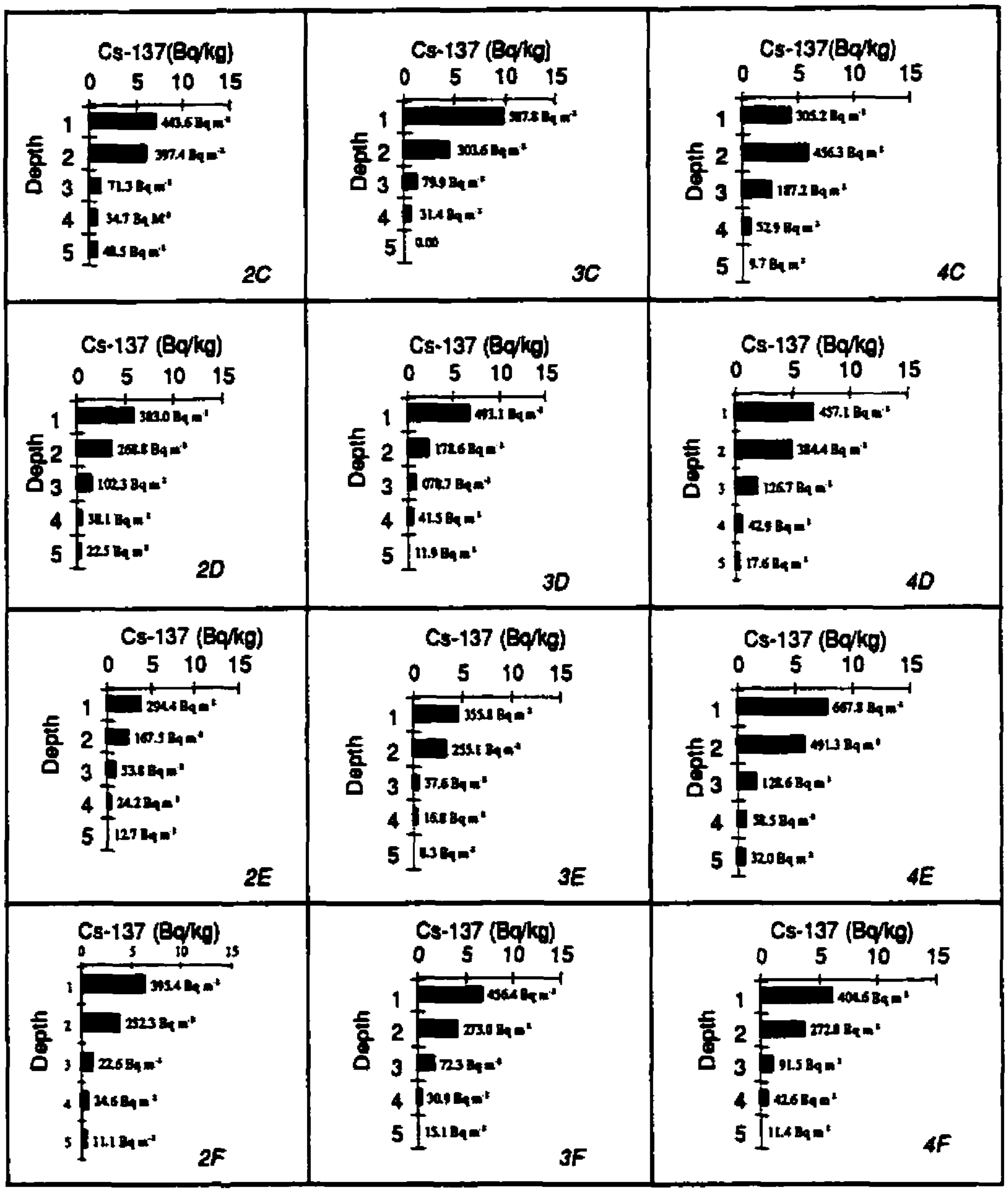


Figure 6.1a Depth and spatial distribution of ^{137}Cs within reference site #1 (UC). The depth increments are 1 (0 to 5 cm), 2 (5 to 10 cm), 3 (10 to 15 cm), 4 (15 to 20 cm), and 5 (20 to 25 cm). The 2C, 3C etc. codes refer to the individual sampling points.

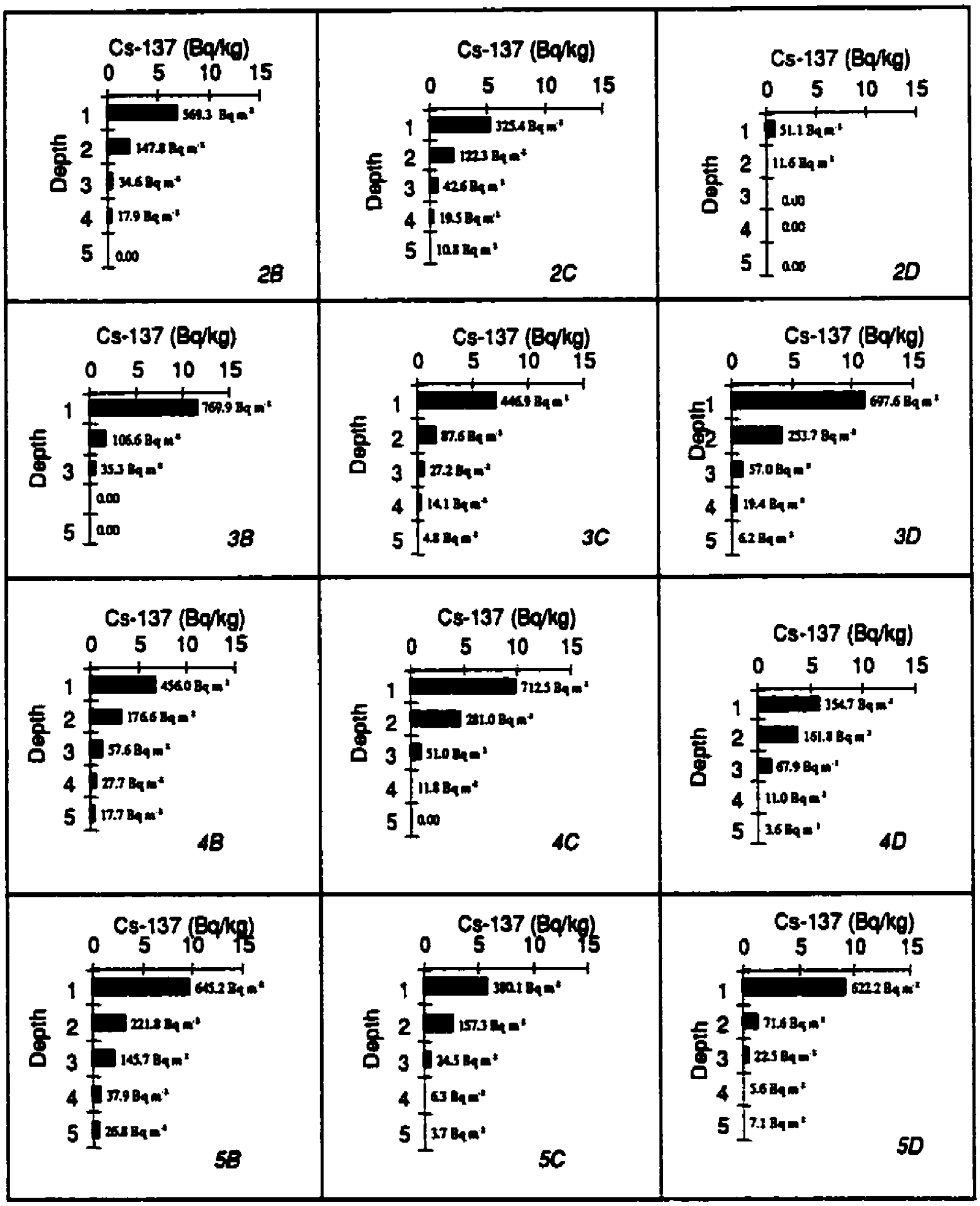


Figure 6.1b Depth and spatial distribution of ^{137}Cs within reference site #2 (LTF1). The depth increments are 1 (0 to 5 cm), 2 (5 to 10 cm), 3 (10 to 15 cm), 4 (15 to 20 cm), and 5 (20 to 25 cm). The 2C, 3C etc. codes refer to the individual sampling points.

A high degree of spatial variability in ^{137}Cs was noted for the two reference sites. The depth distribution of ^{137}Cs from UC (Fig. 6.1a) shows retention of 83% of ^{137}Cs in the upper 10 cm and a sharp decline in activity below this depth. The 0- to 5-cm depth had 50% of total retention while the 5- to 10-cm depth had about 33%. The ^{137}Cs inventory value was between 4 to 10 Bq kg^{-1} and decreased with depth. At sampling point 4C, the concentration of ^{137}Cs in the second depth (5 to 10 cm) was higher than 0- to 5-cm depth. An anthill close to this sampling point may have created a micro backslope, which facilitated movement of soil.

The depth distribution of ^{137}Cs from the second reference site (Fig. 6.1b) was broadly similar in form to that for the first reference site, although one difference may be observed. A sharp decline occurred at below the 5 cm depth (67% of the total inventory was above this depth). Variability within the second reference site (LTF1) was greater with values ranging from 0.81 to 11.5 Bq kg^{-1}. The lowest values were found at site 2D. This sampling point was subsequently identified by villagers as a site for ritual sacrifices and burial and therefore had been subjected to extensive disturbance. This point was removed from subsequent data analysis.

The characteristic sharp decline in ^{137}Cs activity with increasing depth indicates minimal downward translocation. These profile characteristics support the assumption that the majority of mineral soils have the capacity to adsorb and immobilize fallout ^{137}Cs (Walling and Quine, 1995). This finding is especially important for highly weathered soils that have low effective cation exchange capacities relative to temperate region soils. The higher concentration of cesium in the upper 0- to 5-cm at LTF1 than at UC, could be due to the shallow nature of soil.

The total cesium load at UC is about 893 Bq m^{-2} with coefficient of variation of about 24% (Table 6.1). The total load at LTF1 is slightly lower (780 Bq m^{-2}) with a CV of about 27%.

Table 6.1. Areal activity of ^{137}Cs (Bq m^{-2}) in the reference sites. Values shown are means

Table 6.1. Areal activity of ^{137}Cs (Bq m^{-2}) in the reference sites. Values shown are means and standard deviations (in brackets).

	^{137}Cs Load (Bq m^{-2})		C V	
Depth (cm)	**UC**	**LTF1**	**UC**	**LTF1**
0-5	439.6^{a} (109.4)	542.7^{a} (156.5)	24.9	28.8
5-10	308.7^{a} (102.8)	162.6^{b} (66.9)	33.3	41.1
10-15	90.5^{a} (41.3)	51.4^{b} (34.6)	45.6	67.3
15-20	37.3^{a} (12.6)	15.5^{b} (10.7)	33.9	69.0
20-25	17.0^{a} (12.6)	7.3^{a} (8.4)	74.1	115.1
0-25	893.1^{a} (214.7)	779.6^{a} (206.5)	24.0	26.5

Means with the same letter in a given row are not significantly different (α = 0.10 and 0.05). UC= native site, LTF1= 50 years Long-term fallow.

These values are less than 50% of those reported by Abekoe (1996) and Chappell et al. (1998) for Northern Ghana and Niger, respectively. Abekoe (1996) reported a value of 2267 Bq m^{-2} from a hillock in the Northern region of Ghana whereas Chappell et al. (1998) reported 2066 Bq m^{-2} as an estimation of the local reference value from Niger. These high values might be related to the limited number of samples used and/or the aeolian dust trapping capabilities of the sites used in these two studies. The sites used in their studies were isolated groves with dense tree cover, which have high capacity for trapping ^{137}Cs-rich aeolian material. This is reflected in the particle size distribution of the soils studied by the above researchers. Abekoe (1996) reported 51% sand, 33% silt and 16% clay for his reference site. Chappell et al. (1998) found a high positive correlation between silt content and ^{137}Cs. These results, however, indicate the need for detailed study to obtain reference ^{137}Cs values for the region.

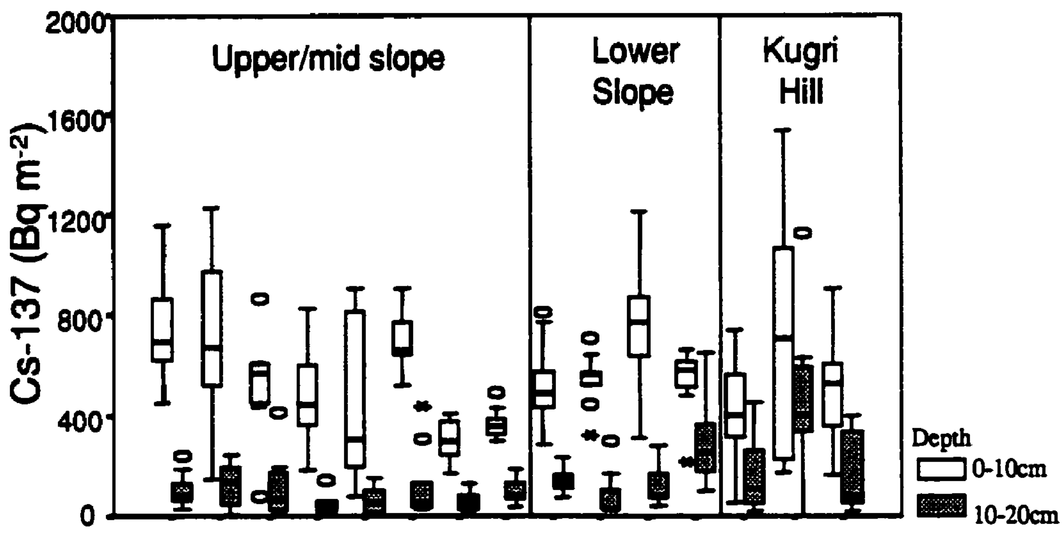
The observed coefficients of variation (15-35%) for cesium at the reference sites are within the moderate variability category of Wilding and Drees (1983). Comparison of the mean ^{137}Cs depth distribution of the two sites showed that there are significant differences between the two sites at all depths at 0.05 level of significance, except the last depth where the difference is significant at only the 0.1 level. There is no significant from the two sites was adopted to overcome the considerable random variability in ^{137}Cs areal activity in soils (Sutherland, 1994; Basher et al., 1995).

6.1.2 Cesium-137 redistribution in the cultivated fields

The depth distribution of ^{137}Cs in the cultivated sites was also characterized by very high concentrations in the upper 0- to 10-cm layer, then a sharp decrease (Fig. 6.2). Four out of seven cultivated sites on the upper and middle slopes of the Varempere association had lost ^{137}Cs compared to the reference inventory. The ^{137}Cs load in the 0- to 20-cm depth for this group of sites varied from about 364 to 846 Bq m^{-2} (Table 6.2). The highest losses were recorded in the compound farms (CF1 and CF2), which are consistent with the farming practices. As discussed earlier, compound farms are permanent cultivation systems where no fertility recovery time is allowed. Fertility is maintained by the use of household refuse. Crop residues are harvested for fuel wood and hence the land is left bare to the hazards of erosion between harvesting and the next planting season.

In the bush farming system, erosion losses were not as high as those measured in the compound farms. Only two out of five bush farms on the upper slopes showed significant losses of ^{137}Cs. The bush farming system is better able to resist erosion because the system involves farming of small patches of land surrounded by natural vegetation, which can act as erosion checks. The fields are further away from the household, complete removal of crop residue is also minimized.

In the lower-slope Varempere soils, no significant changes in ^{137}Cs were observed in any of the sites (Table 6.2) compared to the control sites. Two of the sites showed a slight net loss, whereas the other two sites showed a slight net gain. Overall, the amount of ^{137}Cs in the 10- to 20-cm depth was relatively high compared to the upper slope sites but there was no significant net deposition despite their low position. ABF2 and ABF4 occur at the



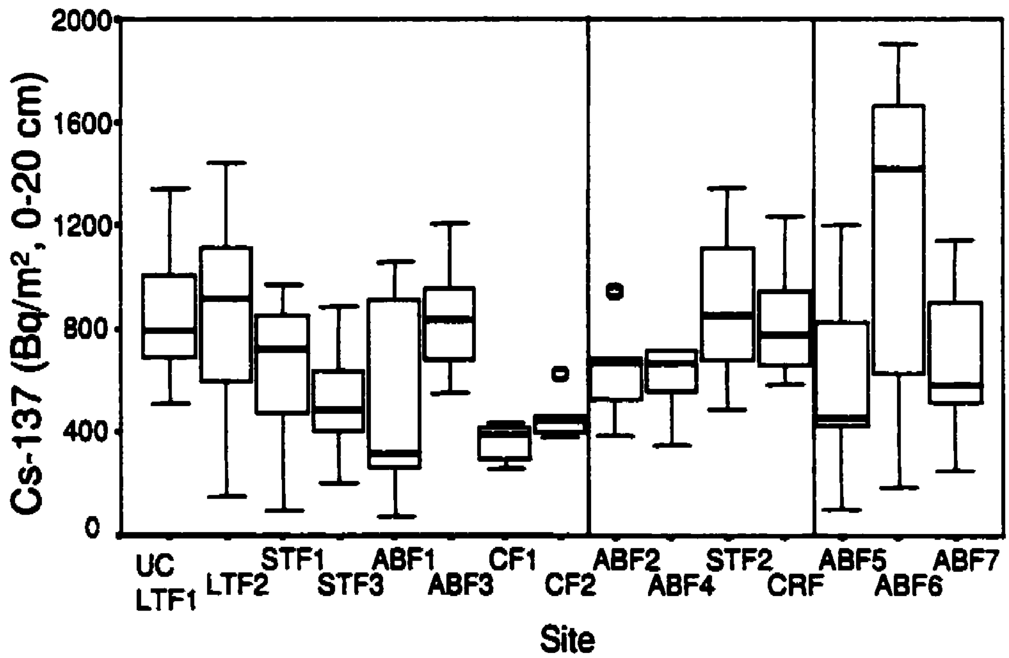


Figure 6.2 Depth distribution of ^{137}Cs and total ^{137}Cs load at the research sites displayed as a box and whisker plot. The box or interquartile range represents the absolute value of the difference between the values of the 25th percentile and the 75th percentile. The upper and lower whiskers or fences extend to values, which represent 1.5 times the spread from the median to the corresponding edge of the box. Data points outside these values are considered outliers and are plotted as individual points.

Table 6.2. Comparison of ^{137}Cs reference inventory with ^{137}Cs in the cultivated sites for the 0- to 20-cm depth. Values shown are mean and standard deviation (in brackets).

Site	Mean (Bq m^{-2})	CV	Ref.-site (Mean diff.)
	Upper/mid slope (Varempere association)		
UC/LTF1	826 (209)	25	-
LTF2	846 (447)	53	-20 ns
CF1	364 (71)	19	463***
CF2	467 (95)	20	360***
ABF1	492 (378)	77	334**
ABF3	820 (203)	25	6 ns
STF1	647 (287)	44	180 ns
STF3	525 (217)	41	302**
	Lower slope (Varempere association)		
ABF2	664 (186)	28	162 ns
ABF4	644 (162.7)	25	182 ns
STF2	894 (286)	32	-67 ns
CRF	841 (214)	25	-14 ns
	Kugri hill catchment area		
ABF5	602 (363)	60	224*
ABF6	1158 (629)	54	-332***
ABF7	680 (300)	44	146 ns

***, **,* significant at 0.01, 0.05, 0.1 level of confidence respectively, unpaired t-test.
ns= not significant.

lower slope positions of the overall slope complex, whereas STF2 and CRF are in pronounced concavities at the base of the slopes. CRF is in the lowermost position of the land surface where the highly eroding CF1 and CF2 are located, yet no significant net deposition occurs. This suggests that most of the eroded material is carried out of the system into rivers with surface runoff.

The lack of net deposition indicated by the ^{137}Cs results is supported by the magnetic susceptibility measurements. Low magnetic susceptibility values were recorded in the lower slope sites despite the very high magnetic susceptibility values of the upland soils. Deposition of soil would have been indicated by a magnetic enhancement of the surface soils (i.e., the deposited upper slope soil) in these lower slope positions. This is especially important for CRF, which is on the lower slope for the highly eroded CF1 land surface.

The ^{137}Cs value of the two sites (ABF5 and ABF6) in the Kugri hill catchment area is consistent with their position within the catchment and support the description of these sites as active erosional/depositional sites. ABF5 was significantly lower than the reference site; ABF6 was significantly higher. ABF6 seemed to be the only deposition site among the 16 sites studied. The amount of ^{137}Cs measured in the second sampling depth of most of the sites was about one-tenth of the first sampling depth, while at ABF6 the second sampling depth values were almost equal to that of the topsoil. The amount of ^{137}Cs measured in the 10- to 20-cm depth at site ABF6 is significantly higher than the amount in the 0- to 10-cm depth of CF1 and CF2. This suggests that ABF6 is experiencing active deposition of sediments from Kugri hill.

6.1.3. Soil loss and gain

The ^{137}Cs measurements were used to estimate the rates of soil loss and gain according to the proportional method equations of Kiss et al. (1985). Walling and Quine (1990) described the limitations of the proportional method, particularly relating to the accumulation of ^{137}Cs at the soil surface between cultivation phases, and suggested it may overestimate rates of erosion. They favored the application of theoretical accounting procedures that are able to represent the aggregate effect of all the redistribution processes operating over the period since the initiation of atmospheric fallout and to take account of any known history of land management at the site.

The calculations for soil loss and gain are normally reported as a mass per area per time (typically Mg ha^{-1} yr^{-1}). These annual values are complicated in the case of the bush farms because of the fallow periods. Although the vegetation cover during the fallow periods does not form a complete cover, we would expect that soil redistribution would be lower during the fallow phase than in the cultivated phase. Hence although the values are reported as an unvarying amount per year, in reality there are probably major year-to-year variations that cannot be assessed using the ^{137}Cs technique.

The highest net soil loss occurred at the two compound farms (Figure 6.3). Net loss (i.e., the loss of soil from the field as a whole) was 18 and 20 Mg ha^{-1} yr^{-1} at CF1 and CF2, respectively. The 20-year fallow site (LTF2) had experienced small amounts of soil gain (6.4 Mg ha^{-1} yr^{-1}). Two of the bush farms on the upper surface had experienced significant net loss of soil (13 Mg ha^{-1} yr^{-1} at STF3 and 8 Mg ha^{-1} yr^{-1} at ABF1) but the remaining two (STF1 and ABF3) showed negligible net loss. Overall, the four bush farms on the upper surface were experiencing a net soil loss of 7.2 Mg ha^{-1} yr^{-1}. This could be considered a tolerable loss if the soils were very deep, such as those found in temperate regions, but for a shallow soil these losses are too high and give cause for concern. According to Morgan (1986) a mean annual soil loss of 11 Mg $ha^{-1}yr^{-1}$ is generally accepted as the maximum permissible but for sensitive areas where soils are thin or highly erodible values as low as 2 to 5 Mg ha^{-1} are recommended.

None of the four sites in the lower slope category showed significant losses or gains relative to the reference sites (i.e., differences were not significant at the 0.1 level in Table 6.2). The two sites on the linear lower slope position (ABF2 and ABF4) had soil losses of 10 and 11 Mg ha^{-1} yr^{-1}, but with a high variability (Figure 6.3). The two sites in

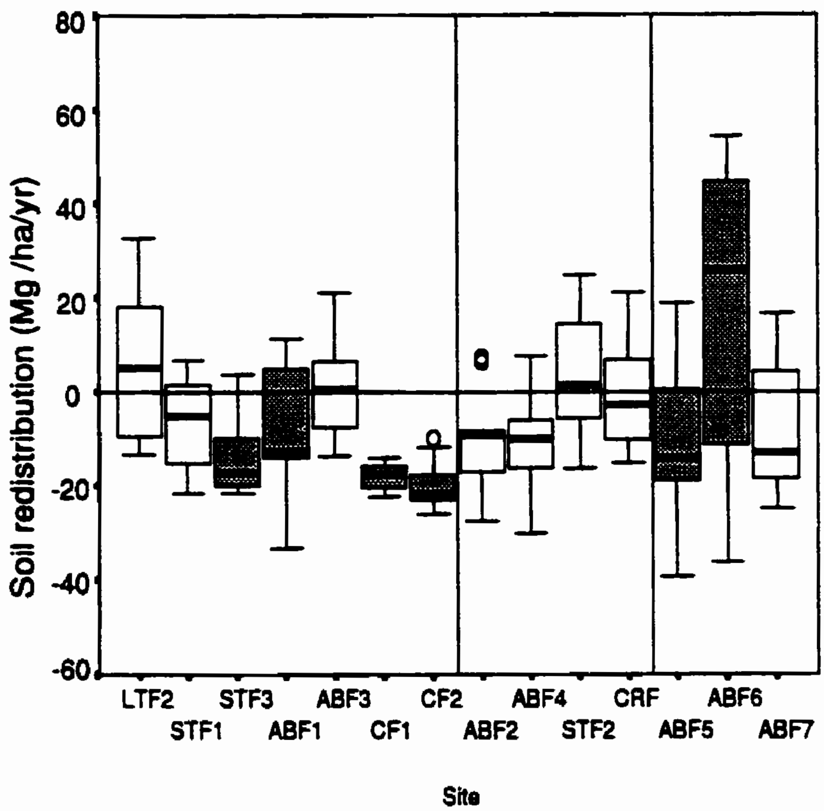


Figure 6.3: Net soil redistribution within each of the cultivated sites. Open boxplots indicate sites where the mean is not significantly different from the control sites; shaded boxplots indicate sites where the mean is significantly different ($\alpha = 0.05$).

Table 6.3. Proportion of sampling points experiencing soil loss or gain at the cultivated sites and the mean loss or gain at these points.

Site	Number of Sampling Points Experiencing Soil Loss	Mean Soil Loss for Sampling Points Experiencing Soil Loss (Mg/ha/yr)	Number of Sampling Points Experiencing Soil Gain	Mean Soil Gain for Sampling Points Experiencing Soil Gain (Mg/ha/yr)
		Upper/mid slope (Varempere association)		
LTF2	4	-10.4	5	12.1
CF1	8	-18.0	0	
CF2	9	-20.0	0	
ABF1	6	-17.1	3	7.7
ABF3	7	-14.4	2	6.7
STF1	6	-10.5	2	5.2
STF3	8	-15.5	1	3.6
		Lower slope (Varempere association)		
ABF2	7	-14.4	2	6.6
ABF4	8	-13.7	1	7.2
STF2	4	-9.2	5	12.8
CRF	5	-9.1	4	11.1
		Kugri hill catchment		
ABF5	6	-20.3	3	10.3
ABF6	4	-15.4	5	39.7
ABF7	6	-16.8	3	10.9

the concave lower slope positions did not show significant gains of soil through deposition, although their position in the landscape would have indicated a high potential for deposition.

Within-field redistribution was evident at most of the sites (Figure 6.3). Only the two compound farms have all their sampling points below the reference level; all other sites have a spread of values above and below the reference line. At the remainder of the sites there is evidence for considerable within-field redistribution of ^{137}Cs and soil (Table 6.3). The net soil loss from a given site reflects the balance between sampling points that experienced soil loss and those that experienced gain. For example, net loss is high at site STF3 where 8 out of 9 points had soil loss and was low at CRF where roughly equal proportions of sampling points showed loss or gain. The rates of soil loss at those points that experienced loss is not high by the standards of other ^{137}Cs studies – mean soil loss only exceeded 20 Mg ha^{-1} yr^{-1} at two sites.

6.2 Rapidly changing indicators of soil quality

Biochemical and chemical indicators of soil quality are those properties that are affected by agronomic practices and which may change rapidly. The biochemical and chemical properties assessed were soil organic carbon (SOC), total N, total P, effective cation exchange capacity (ECEC) and base saturation, pH, and electrical conductivity (EC). Changes in these properties under the different farming practices and the relationships between these properties and soil redistribution were explored. An attempt was made to model the impact of soil erosion on organic matter dynamics.

6.2.1. Soil organic carbon

The highest levels of soil organic carbon (SOC) were observed in the uncultivated site (UC) (Fig. 6.4). A total of 34 Mg ha^{-1} occurs in the surface 20 cm of the soil. SOC is highest in the surface 0- to 5-cm layer and declines markedly in the 5-10 cm increment. The lower increments show relatively consistent values for SOC, indicating that considerable surface enrichment of SOC exists in the surface soil of the uncultivated site. The high SOC in the surface layer of the uncultivated site is probably related to litter accumulation from woody vegetation (Nye and Greenland, 1964; Juo and Manu, 1996).

In general, SOC at the uncultivated site is low compared to organic carbon content of forest zones and temperate regions (Pennock et al., 1994a; Gregorich and Anderson, 1985; Nye and Greenland, 1964). This difference is attributed to differences in vegetation and climatic conditions, especially temperature and rainfall. The characteristic high temperature and rainfall of this semiarid region encourage rapid decomposition of organic matter and release of nutrients resulting in lower accumulation of residual organic matter compared to cooler soils (Juo and Manu, 1996).

SOC content of LTF1 (Fig. 6.4) is much lower than UC despite the 50-year fallow period in LFT1. The total amount of SOC in LTF1 was about half that of UC (18 vs. 34 Mg ha^{-1}). When the depth distribution of the two sites are compared it appears that the 0- to 5-cm layer at LTF1 corresponds to the 5- to 10-cm layer at UC. This site had been cultivated prior to ^{137}Cs deposition and the cesium results indicate minimal loss from this site in the past 30 years. Hence, the decreased SOC levels are primarily due to loss during the period of cultivation. Overall, the results from LTF1 indicate a limited potential for recovery of SOC levels in these soils even with a long fallow period.

The SOC levels at LTF1 are very similar to those for the 20-year fallow site (LTF2). Both the total amount (Figure 6.5) and the depth distribution of SOC at the two sites (Table 6.4) are similar. At both sites the SOC levels are at approximately 50% of those at the uncultivated site.

The SOC content for all upper slope, bush farm or compound farm sites were lower than those of UC or the long-term fallow sites (Figure 6.5). The lowest value (6.5 Mg ha^{-1}) occur at CF2 and the highest (13.4 Mg ha^{-1}) at ABF1. These represent a 60-80% reduction in SOC values from the uncultivated site. The losses of SOC in the compound farms are high but can, in part, be made up by the addition of organic wastes.

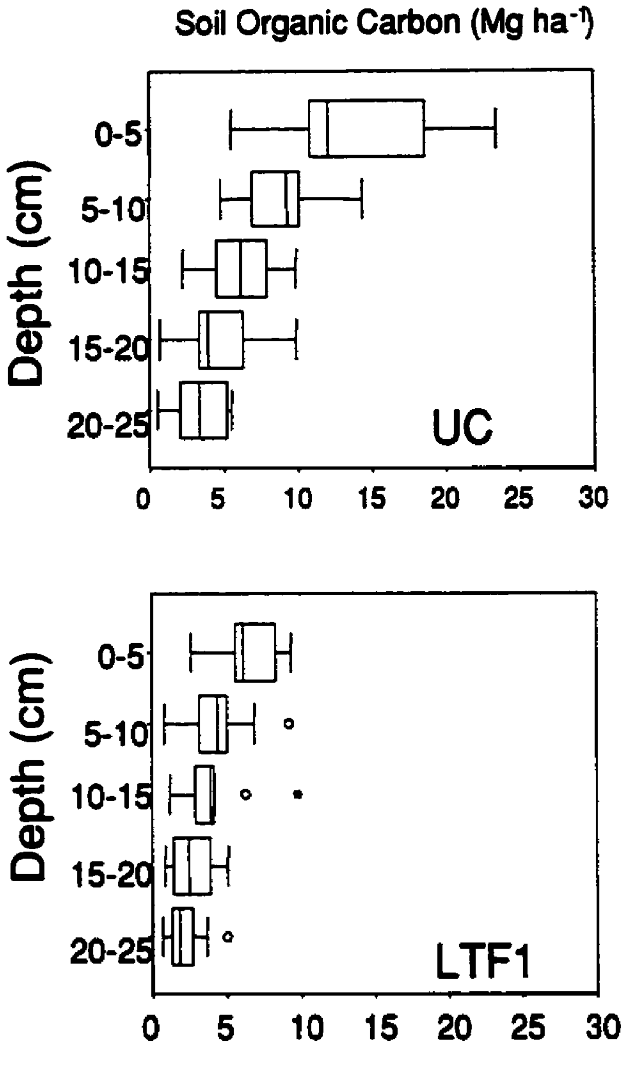


Figure 6.4: Depth distribution boxplots of soil organic carbon at sites UC and LTF1.

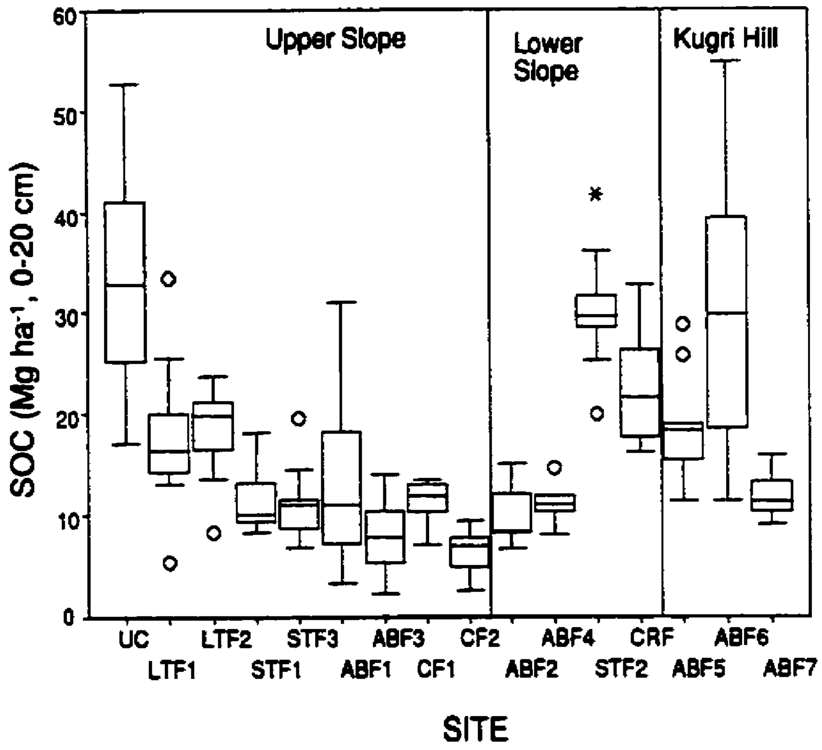


Figure 6.5: Boxplots of soil organic carbon (Mg ha^{-1}, 0-20 cm) at the research sites.

Table 6.4: Soil organic carbon levels (mean and standard deviation in brackets) in the 0-10-cm and the 10- to 20-cm depths at the research sites.

Site	Soil Organic Carbon (Mg ha^{-1})	
	0-10 cm	**10-20 cm**
	Upper slope (Varempere association)	
UC	23.0 (8)	11.0 (5)
LTF1	11.1 (4)	6.7 (4)
LTF2	12.1 (4)	6.4 (3)
STF1	7.8 (3)	3.7(2)
STF3	7.0 (3)	4.2 (2)
ABF1	8.8 (5)	4.6 (4)
ABF3	4.5 (3)	3.7 (2)
CF1	7.9 (2)	3.5 (2)
CF2	4.7 (2)	1.7 (1)
	Lower slope (Varempere association)	
ABF2	7.1 (2)	2.8 (2)
ABF4	7.2 (2)	3.7 (1)
STF2	20.4 (5)	10.0 (2)
CRF	12.5 (3)	10.2 (5)
	Kugri hill catchment	
ABF5	10.5 (3)	8.4 (3)
ABF6	14.7 (8)	14.0 (7)
ABF7	6.6 (1.0)	5.3 (2)

The losses in the bush farms cannot be readily offset by the addition of organic material and may represent a graver loss in terms of soil productivity.

Similar observations were made in other parts of the region. For example, Jones (1973) compared organic matter content of cultivated soils in the Guinea Savannah zone of Nigeria and reported 5.8 g kg^{-1} for cultivated soils compared to 10.3 g kg^{-1} for uncultivated soils. Under cultivation, aeration and microbial activities increase, thus there is an oxidation of organic matter. This is very pronounced under continuous low input agriculture being practised in the region (Stoop, 1987).

Inputs into the system depend on socioeconomic status of the farmer as can be seen by greatest decreases in organic carbon occurring at CF2 and ABF3. Even though the low SOC in CF2 is to be expected because it is under low input permanent cultivation, the loss is high compared to CF1, which is also under permanent cultivation. CF2 is a compound farm owned by a poorer family whereas the chief of the village owns CF1. The chief of the village has a large number of livestock, which provide organic manure for the compound farm. Addition of household manure is an important source of SOC in the compound farms. ABF3 is used by a migrant farmer who may not be as committed to the land as are the indigenous people.

The results for the lower slope soils and the soils of the Kugri catchment cannot be directly compared to those for UC because the assumption of similar initial conditions cannot be supported. A major difference exists between sites ABF2 and ABF4 and sites STF2 and CRF for the lower slope sites. The former two sites have SOC levels comparable to the lowest of the upper slope soils, whereas the SOC levels at the two sites in the concave lower slope positions (STF2 and CRF) are higher than even the long-term fallow sites. The higher SOC values at the latter two sites may not be the result of deposition of organically enriched soil in the past 30 years (since no deposition is indicated by the ^{137}Cs results) but must reflect different conditions for either organic matter production or decomposition. Hence although these four lower slope soils share similar pedological characteristics, they appear to have very different biochemical regimes.

The results from the three soils of the Kugri catchement support the redistribution results from the ^{137}Cs technique. The overall amount of SOC in the depositional site (ABF6) is similar to site UC (29 vs. 34 Mg ha^{-1}, respectively) and the amount in the 10- to 20-cm layer is equal to that in the 0- to 10-cm layer (Table 6.4). The lack of a clear depth profile for SOC in depositional sites has been widely observed in other studies. SOC levels in site ABF5 are comparable to the long-term fallow sites and are considerably higher than the bush farm sites on the upper soil surface despite the continuous cultivation of this surface. Site ABF7 is not experiencing active soil redistribution and has SOC levels consistent with the upper slope soils discussed above.

6.2.2. Cumulative soil loss and SOC dynamics

The simple model developed in Section 3.3.7 was used to predict the effect of erosion on SOC levels for the upper slope soils. The intent of the model is to determine the importance of erosion in the observed loss of SOC. Essentially, the model assumes that the initial SOC content of the upper slope soils was equal to that of the uncultivated site and that export of SOC proportional to the soil loss occurs each year after the site is broken

The initial SOC levels used in the model are the SOC contents of the five soil layers measured at UC (14.2, 8.9, 6.2, 4.4, and 3.4 Mg ha^{-1} for the five increments from the surface to 20- to 25-cm layer, respectively). Specific mass was calculated as a product of bulk density of the respective layers and sampling depth. Soil loss results in loss of surface soil and the transfer of an equivalent depth of soil (with a specified SOC content) from each successive depth increment to the increment overlying it. The SOC content of the lowermost layer was constant for the duration of a model run.

An enrichment factor of 1 was used for all model runs. This assumes that the SOC of the sediment removed from the site equals the SOC content of the fine fraction

Table 6.5: Simulated change in SOC levels (0-20 cm) with soil losses of 7.5 Mg ha^{-1} yr^{-1} (average for the upper slope bush farms) and 19 Mg ha^{-1} yr^{-1} (average for the upper slope compound farms). Initial SOC levels are those for site UC (33.9 Mg ha^{-1}).

Years after Time 0 (Initiation of Cultivation)	SOC Remaining for 7.5 Mg ha^{-1} yr^{-1} Rate (Mg ha^{-1})	SOC Remaining For 19 Mg ha^{-1} yr^{-1} Rate (Mg ha^{-1})
10	32.1	29.4
20	30.2	25.3
30	28.5	22.2
40	27.1	19.9
50	25.5	18.2
60	24.2	16.9
70	23.0	16.2
80	22.1	15.6
90	21.0	15.2
100	20.2	14.9
110	19.5	14.8
120	18.8	14.7
130	18.2	14.6

of the bulk soil and no preferential loss of SOC occurs. As such, the losses represent a minimum amount of SOC loss that could occur at a given erosion rate.

Two erosion rates are used for the model. The bush farms (STF1, STF3, ABF1, ABF3) on the upper surface showed an average loss of 7.5 Mg ha^{-1} yr^{-1}based on the ^{137}Cs results. The compound farms (CF1, CF2) on the upper surface had an average loss of 19 Mg ha^{-1} yr^{-1}. Clearly, (as discussed earlier) the actual erosion rate in any given year may be higher or lower than this value but it is assumed that this average value reflects total soil loss over the period of measurement.

Using these values, it is predicted that the change in SOC with time is characterized initially by a rapid decrease, followed by a more gradual decrease and a near-constant level thereafter (Table 6.5). The soils of the study region have been cultivated for approximately 100 years. After soil loss at the two average rates for 100 years, the bush farms should have approximately 60% of their original organic carbon remaining (20.2 Mg ha^{-1}) and the compound farms should have 44% remaining (14.9 Mg ha^{-1}) (Table 6.5).

Most of the cultivated fields have lost substantially more SOC than the model results would account for. The four bush farms have an average SOC level of 11 Mg ha^{-1} (range from 8.2 Mg ha^{-1} at ABF3 to 11.5 Mg ha^{-1} at STF1) which is well below the erosion-induced SOC level of 20 Mg ha^{-1} predicted by the model. Clearly, some degree of organic carbon input occurs in the fallow periods, so the very low observed SOC levels indicates that the non-erosion SOC losses from these sites is at least of a similar magnitude to the export of SOC due to erosion. The two compound farms have an average SOC content of 9 Mg ha^{-1}, which is again well below the amount predicted by the model. These farms receive organic inputs through animal and human wastes, so the total SOC loss due to mineralization and crop removal is likely to be significantly higher than the erosion-induced loss.

Erosion appears to be an important process in soil organic matter loss, but it may not be as important as in combination with the process of crop removal. Soil regeneration in these agroecosystem is very slow because outputs exceed inputs. The chemical composition of organic inputs also change when vegetation is altered from indigenous species to crop species resulting in low quality and quantity organic matter. Crop residues decompose more rapidly in agroecosystems than in natural ecosystems and nutrient cycling becomes less tightly closed. The use of this land without adequate input supply will result in very severe degradation of the soil resource.

6.2.3 Total nitrogen

Total soil N values closely parallel SOC (Table 6.6). In the uncultivated site, 46% of the total amount was in the 0- to 5-cm depth, 28% was in the 5- to 10-cm depth. The third depth and the fourth depth had 14% and 12 % respectively. A similar trend was observed in the long term fallow and all the other sites. Total nitrogen in the UC site was more than twice the measured values in the long-term fallow (LTF1) and the upper horizon of LTF1 seemed truncated, as was observed in the SOC depth distribution. Total N in all the cultivated sites also followed the same trend as SOC except that all sites including STF2 recorded a significant decrease of about 50 % or more (Table 6.5). ABF2, ABF3, CF2, and ABF4 had very low values for total N.

The similarities for soil N and SOC is to be expected. Most soil N occurs as part of organic compounds. Except where large amounts of chemical fertilizers have been applied, inorganic N seldom accounts for more than 1 to 2 % of the total N in the soil. The mineral forms of N are mostly quite soluble in water, and therefore, easily lost from the soil through leaching.

The C:N ratios range from 7 to 15 for all sites. All the upper/mid slope sites except CF2 have C:N ratios of about 11. CF2 seems to have proportionally more N than C, no clear explanantion can be offered. There were remanats of the previous year's crop of groundnuts, which could account for this result. The concave lower slope sites (CRF and STF2) have high SOC levels but also have higher C:N ratios, indicating a lower quality organic material in terms of N mineralization potential. The C:N ratios of the Kugri hill sites are similar to those of the upper and midslope sites.

Crop production in these soils will depend on organic matter maintenance since little N fertilizer is added outside of the compound farms. The total N losses from the soil fines may be of more significance than SOC losses because Abekoe (1996) generally found high C:N ratios for concretions, indicating that the concretions have less N relative to C. As such, there would be no reliable source of N replenishment in these soils.

Table 6.6. Total nitrogen (mg kg^{-1}) in the soils at the different sites. Values presented are means and standard deviation (in brackets).

	Total Nitrogen (mg kg^{-1})		C:N Ratio
Site	0-10 cm	10-20 cm	0-20 cm
	Upper/mid slope (Varempere association)		
UC	1549 (516)	664 (202)	11
LTF1	743 (188)	579 (137)	11
LTF2	881 (334)	652 (182)	11
STF1	637 (208)	420 (136)	10
STF3	500 (90)	482 (98)	10
ABF1	827 (345)	510 (163)	11
ABF3	489 (84)	131 (18)	10
CF1	661 (214)	500 (88)	10
CF2	432 (128)	226 (42)	7
	Lower slope (Varempere association)		
ABF2	404 (66)	253 (82)	9
ABF4	416 (74)	288 (56)	9
STF2	954 (180)	542 (124)	15
CRF	636 (120)	502 (158)	12
	Kugri hill catchment		
ABF5	715 (120)	646 (127)	11
ABF6	848 (355)	859 (254)	13
ABF7	497 (84)	479 (145)	9

Site = Native site (UC), Active Bush Farm (ABF), Short-Term Fallow (STF), Long-Term Fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF)

6.2.4 Effective Cation Exchange Capacity (ECEC)

The ECEC values also strongly reflect soil organic carbon content of the soils. The ECEC values in the two reference and cultivated sites were similar in trend to the SOC and TN values in that there was maximum concentration in the surface layer.

Values in the uncultivated site (UC) were higher than the long-term fallow site (LTF1). The ECEC values for surface (0- to 10-cm) layer varied widely from 7.79 cmol kg^{-1} for STF2 to 1.56 cmol kg^{-1} for ABF4 and decreased with depth (Table 6.7).

ECEC values higher than 4 cmol kg^{-1} have sufficient cation exchange capacity to prevent serious leaching losses (Sanchez, 1976). Values recorded for UC, STF2, ABF5, ABF6 and CRF are above this threshold; all others are below this threshold. The ECEC values seemed to be also related to soil redistribution. The high ECEC in SFT2 and CRF could probably be due to high SOC and relatively high clay content of these sites compared to the other sites.

Decreases in total soil losses of ECEC with cultivation are probably much lower for sites with significant nodule contents. Abekoe (1996) found that the ECEC for concretions was basically the same as for fines. Therefore, the sites that are most at risk are those with low concretion contents, where the loss of ECEC cannot be effectively replaced.

Calcium (Ca) and magnesium (Mg) were the dominant exchangeable cations in all the surface soils, as was expected for this region. Other cations including ammonium-N were relatively low. Exchangeable Ca and Mg accounted for more than 80% of the effective cation exchange capacity in the surface layers (0 to 10 cm, 10 to 20 cm) for all sites (data not shown).

Table 6.7. Effective Cation Exchange Capacity (ECEC) values of the 0- to 20-cm depth of soils at the study sites. Values presented are mean and standard deviation (in brackets).

Site	ECEC (cmol kg^{-1}) 0-10cm	ECEC (cmol kg^{-1}) 10-20cm
	Upper/mid slope (Varempere association)	
UC	6.6 (2.8)	3.3 (1.4)
LTF1	3.9 (1.2)	3.2 (2.1)
LTF2	1.9 (0.9)	1.2 (0.6)
STF1	2.5(1.3)	1.3 (0.5)
STF3	2.1 (0.6)	1.2 (0.4)
ABF1	2.6 (1.4)	1.2 (1.0)
ABF3	2.6 (0.6)	2.1 (0.7)
CF1	1.9 (0.5)	1.2 (0.4)
CF2	2.2 (0.7)	1.7 (0.3)
	Lower slope (Varempere association)	
ABF2	1.7 (0.5)	1.2 (0.5)
ABF4	1.6 (0.4)	1.0 (0.3)
STF2	7.3 (1.9)	5.3 (1.6)
CRF	5.4 (0.7)	6.2 (1.0)
	Kugri hill catchment	
ABF5	4.4 (2.0)	4.9 (3.7)
ABF6	7.0 (3.2)	7.6 (1.5)
ABF7	1.7 (0.3)	1.5 (0.3)

Native site (UC), Active Bush Farm (ABF), Short-Term Fallow (STF), Long-Term Fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF)

6.2.5 Total phosphorus

The distribution of total soil P in the fine soil fraction within and among sites differs from the previous properties examined. Phosphorus was more evenly distributed in all depths at both UC and LFT1 as opposed to the surface concentration observed in the distribution of SOC and TN (Fig. 6.5 a and b). The absence of surface concentration means that total soil P is much less sensitive to surface soil loss than the previous properties insofar as the sub-surface reservoirs can readily replace the P lost in surface sediment. As well, the mean value for UC was significantly lower than LTF1, whereas the reverse was true for SOC and N.

There were few clear relationships between the total P values of the study sites and either cultivation history or landscape position (Table 6.8). The two compound farms have higher P levels than the four bush farms on the upper slope surface, indicating that replenishment of P levels through organic additions and ashes at the compound farms may be offsetting losses through crop removal. In the lower slope soils the two sites on the linear segments (ABF2 and ABF4) have lower levels than the two sites in the concave segments. The levels at ABF2 and ABF4 are very similar to the soil on the older colluvial surface in the Kugri Hill catchment. The two remaining sites in the Kugri hill catchment have high P levels, with the highest value at site ABF6. This is the site experiencing active deposition of sediment from the Kugri hill catchement, and the high P levels in both layers may indicate that the parent materials in this area are inherently high in P compared to the parent materials in the rest of the landscape.

The low total P values recorded in all the sites including the reference sites was consistent with reports from different parts of sub-Saharan Africa. Acquaye and Oteng (1972) obtained values ranging from 104 to 270 mg kg^{-1} from different ecological zones of Ghana. From the savanna region of Ghana, Owusu-Bennoah and Acquaye (1989) reported 60 to 173 mg kg^{-1} and Abekoe (1996) obtained values ranging from 88 to 785 mg kg^{-1} from the same region. Total P measured in some soils of Niger was between 29

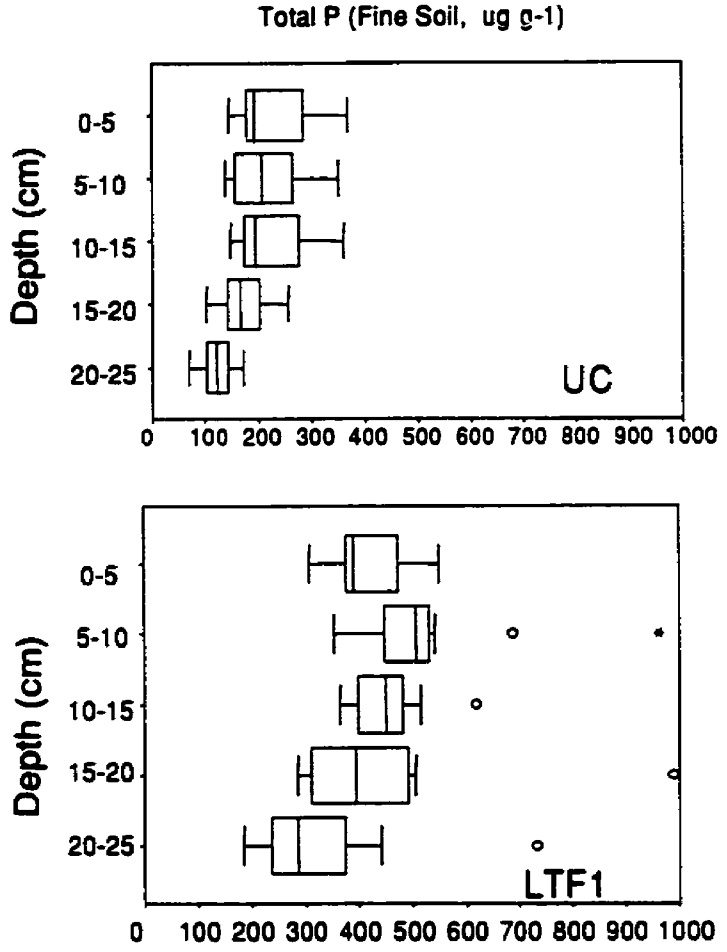


Figure 6.5: Depth distribution boxplots for total soil P (ug g^{-1}) for sites UC and LTF1.

and 349 mg kg^{-1} with a mean of 109 mg kg^{-1} (Manu, et al., 1991) and in Nigeria, it varied from as low as 79 mg kg^{-1} to as high as 1410 mg kg^{-1} (Ibia and Udo, 1993).

Tropical soils are known to suffer from multiple nutrient deficiencies, but particularly P. Reports from different parts of West Africa indicate that both total and available P contents of soils vary, but values are generally low (Manu et al., 1991; Ibia and Udo, 1993; Owusu-Bennoah and Acquaye, 1989; Abekoe 1996). Nye and Bertheux (1957) attributed the low content of P in most Ghanaian savanna soils to the low content of mineral apatite in the parent rocks, the great age of the soils, and the intense weathering to which the rocks have been subjected, as well as poor organic matter cycling and high P sorption capacity of the soils. Most often, the adsorbed P is not readily available to plants.

The role of concretions in soil P cycling is important. Soil P undergoes both pedological and short-term biological transformations in soils and landscapes. Biological transformations may be important in the short-term while the long-term availability is often governed by pedological transformations. Soil P is mostly derived from parent materials (Ca-phosphate and apatite) or from fertilizer sources; environmental inputs are usually negligible (Tiessen, 1991). During the weathering of soils, Ca and other bases are lost through leaching and secondary Al and Fe oxides are formed. These Al and Fe oxides act as P sinks inducing a shift from Ca-P to Al-P and Fe-P forms which become occluded with time (Tiessen, 1991). Total P balance remains the same during these transformations which means that even though total P may be great, phosphorus availability for plant growth may be a limiting factor. With soil development considerable losses are observed, resulting in less total and labile P in many old and well developed soils of the tropics (Tiessen, 1991). Abekoe (1996) found that total P of concretions is higher than total P of soil fines; however, labile P for soil fines was higher than that of the concretions.

Table 6.8: Total soil P (ug g^{-1}) of the 0- to 20-cm depth of soils at the study sites. Values presented are mean and standard deviation (in brackets).

Site	Soil Phosphorus $\mu g\ g^{-1}$ 0-10cm	10-20cm
	Upper/mid slope (Varempere association)	
UC	222.9 (65.0)	173.4 (44.2)
LTF1	551.3 (52.5)	437.6 (201.7)
LTF2	157.5 (52.2)	126.4 (37.1)
STF1	151.3 (38.1)	151.1 (33.1)
STF3	92.5 (9.9)	104.4 (18.1)
ABF1	205.2 (71.5)	173.7 (49.3)
ABF3	130.9 (19.3)	135.2 (23.1)
CF1	295.8 (89.4)	278.9 (67.9)
CF2	214.6 (32.7)	216.5 (34.6)
	Lower slope (Varempere association)	
ABF2	80.7 (11.0)	75.6 (17.4)
ABF4	62.8 (8.4)	57.4 (16.3)
STF2	309.6 (91.9)	195.1 (45.7)
CRF	179.3 (29.3)	159.7 (24.9)
	Kugri hill catchment	
ABF5	343.9 (146.4)	312.3 (158.1)
ABF6	766.0 (184.4)	655.5 (119.1)
ABF7	71.2 (11.4)	76.7 (18.1)

6.2.6 Base saturation

Base saturation of the surface soils was generally high, with values ranging from 98% to 56% (Table 6.9), with only two sites (CF1 and ABF1) below 60%. The base saturation of the remaining fourteen sites was above 70%. Base saturation in the soil at UC was significantly higher than LTF1. There was a slight reduction in base saturation with depth but this was not significant. A clear difference exists between the soils of the upper and lower slope positions – the lower slope soils all have base saturation in excess of 90% in both 0- to 10-cm and 10- to 20-cm increments, whereas the average for the upper slope sites, considered as a whole, is 75% for the first increment and 61% for the second increment.

Similar high base saturation results were reported from other parts of the region (Hauffe, 1989; Tiessen et al., 1991a; Drees et al., 1993, Abekoe, 1996). The high base saturation is not consistent with the pedogenesis and erosion processes operating in the region. As indicated in section 2.1.1, soils of the study region are considered low base soils developed from parent materials that were virtually devoid of weatherable primary minerals and bases. The researchers mentioned above further investigated this inconsistency and suggested aeolian deposition as the source of weatherable minerals rich in basic cations. The climate of the study region is semiarid with a pronounced dry season of about 7 months, during which dry north-easterly winds of Harmattan predominate. The Harmattan is a dust-laden wind, which occurs in the countries along the Gulf of Guinea during the dry season. The nutrient and base mineral status of the dust is reported to be substantially greater than the native soil and may serve as a nutrient renewal source. From identification of minerals in aeolian dust from 10 widely scattered sites around the world, Syers et al. (1972) concluded that dust accessions could be a rejuvenating process for strongly leached and highly weathered soils. Feldspars, chlorites, and micas were components of the dust although quartz was dominant. These minerals would add K, Ca and Mg to soils over the long-term. Calcite and dolomite were also present in some samples, and those would add these nutrients.

Table 6.9. Base saturation (BS) values of the 0- to 20-cm layer of soils at the study sites. Values presented are mean and standard deviation (in brackets).

Site	Base Saturation (%)	
	0-10cm	**10-20cm**
	Upper/mid slope	
UC	92 (5)	77 (20)
LTF1	76 (9)	66 (10)
STF1	74 (15)	52 (17)
ABF1	55 (27)	40 (23)
CF1	57 (2)	41 (9)
LTF2	75 (29)	65 (31)
STF3	77 (19)	53 (22)
CF2	82 (3)	73 (9)
ABF3	91 (6)	81 (15)
	Lower slope	
ABF2	94 (1)	91 (2)
ABF4	92 (8)	91 (4)
STF2	95 (4)	92 (4)
CRF	98 (1)	96 (2)
	Kugri hill catchment	
ABF5	83 (11)	77 (16)
ABF6	92 (6)	92 (7)
ABF7	90 (4)	77(14)

Native site (UC), Active Bush Farm (ABF), Short-Term Fallow (STF), Long-Term Fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF)

Tiessen et al. (1991a) also found evidence of additions of Ca, Mg, and K in airborne dust at Nyankpala in northern Ghana, with accessions during a single year providing bases equivalent to 1% of the effective exchange capacity of soils to a depth of 10 cm. The combined amounts of Ca, Mg, K, and Na were equivalent to about 10 kg ha^{-1}. Furthermore, the dust also added long-time reserves in the form of feldspars and micas. One dust sample contained 5.6% K_20, 0.67% Ca, and 0.59 % Mg which would be released slowly and become available to plants over the long term. Another report on addition of nutrient elements in airborne dust from the Sahara comes from Niger. Drees et al. (1993) found that yearly additions were approximately 10 kg ha^{-1} of exchangeable and water soluble Ca, Mg, K, and Na. Less than half of the K and Na were in exchangeable form.

6.2.6 Soil pH and electrical conductivity (EC)

There was no significant difference between the pH values measured for the two reference sites (Table 6.8) and changes in value with depth were also very small. However, there was a clear distinction between upper and lower slope sites. The upper slope sites had higher values than those sites in the lower slope positions. The low pH measurements recorded in the lower slope position sites are inconsistent with their high base saturation status. It could however, be related to the drainage conditions and Fe mineralogy. Poor drainage conditions create anaerobic conditions, which encourage acidification processes such as nitrification and leaching. The Fe_o/Fe_d ratio of these sites is more than 0.2, which is an indication of poor drainage conditions.

ABF5 and ABF6 also have high Fe_o/Fe_d ratios but higher pH, which may indicate that these sites are younger than all the other sites. Leaching depletes the upper horizons of Ca and other basic cations (Brady and Weil, 1996) leading to a preponderance of hydrogen and aluminum ions generated through organic matter decomposition and other weathering processes

Table 6.10. pH and Electrical Conductivity (EC) of the 0- to 20-cm layer of soils at the study sites. Values presented are mean.

	pH		EC (mS cm^{-1})	
Site	**0-10 cm**	**10-20 cm**	**0-10 cm**	**10-20 cm**
		Upper/mid slope (Varempere association)		
UC	7.4	7.3	0.16	0.07
LTF1	7.3	6.8	0.03	0.02
STF1	7.6	7.3	0.03	0.02
ABF1	7.5	6.9	0.04	0.03
CF1	7.2	7.1	0.03	0.02
LTF2	7.1	6.6	0.03	0.02
STF3	7.0	6.9	0.02	0.02
CF2	6.9	6.6	0.04	0.02
ABF3	6.7	6.4	0.03	0.02
		Lower slope (Varempere association)		
ABF2	6.5	6.2	0.03	0.02
ABF4	6.4	6.1	0.06	0.03
STF2	6.4	6.3	0.02	0.02
CRF	6.6	6.6	0.03	0.03
		Kugri hill catchment		
ABF5	7.1	7.2	0.03	0.02
ABF6	7.1	6.9	0.07	0.06
ABF7	6.4	6.4	0.03	0.01

Native site (UC), Active Bush Farm (ABF), Short-Term Fallow (STF), Long-Term Fallow (LTF), Compound Farm (CF) and Compound Rice Farm (CRF)

In general, the surface pH values are higher than expected, ranging between 6.1 to 7.5. The high pH of surface soils in most of the profiles could be attributed to the semiarid condition, the release of ash to the soil from annual burning as a means of land clearing, and the annual influx of high base soils of the Harmattan dust. The low rainfall regime of the region discourages leaching and therefore the soils are often neutral or basic in reaction.

The mean EC values for all sites are in the non-saline range. However, values measured at UC were significantly higher than the other sites. Electrical conductivity is a good indicator of soil quality because the soluble salt concentration of the soil solution is an important determinant of the suitability of the soil for plant growth (Larson and Pierce, 1991). Changes in EC as a result of soil management can be used to make inferences about the effect of farming practices on soil water storage, the efficiency with which crops use moisture, and the redistribution of water within the landscape.

6.2.8 Spatial variability of the dynamic properties

The within-site random variability in the dynamic properties is an important constraint on their usefulness of as an indicator for changes in soil quality. Generally, the higher the variability within a site, the greater the number of samples that must be taken to achieve a given confidence level for assessing the significance of observed changes.

Soil organic carbon, total nitrogen, effective cation exchange capacity and total phosphorus were the most highly variable chemical properties (Table 6.11). The high variability observed in SOC could be due in part to the spatial distribution of vegetation and leaf-litter and to variability in micro topography. Plant biomass is an important control on SOC accumulation that, in turn, depends on the type of vegetation. Trees produce high above-ground biomass. Grasses produce less biomass above ground. A vegetation type with a mixture of trees and grasses is bound to have variable amounts of SOC across the landscape and within fields. The natural savanna vegetation of mixed grasses and trees found in the study area is reflected in the high variability in SOC values measured within the uncultivated site (UC) and the fallow sites (LTF1, LTF2, STF1, and

Table 6.11. Coefficients of variability for chemical and biochemical properties within study sites (0-10 cm depth)

	Coefficient of Variation (%)					
Site	SOC	TN	ECEC	TP	BS	pH
			Upper/mid slope (Varempere association)			
UC	34	32	42	26	5	4
LTF1	38	23	30	60	11	5
STF1	41	34	52	25	20	8
ABF1	68	60	53	44	48	8
CF1	23	31	26	31	3	7
LTF2	44	40	47	35	39	6
STF3	47	40	28	33	24	1
CF2	49	30	31	16	4	10
ABF3	56	13	23	11	6	3
			Lower slope (Varempere association)			
ABF2	23	12	29	7	1	5
ABF4	27	20	26	9	9	11
STF2	26	16	26	26	4	5
CRF	21	50	13	17	1	3
			Kugri hill catchment			
ABF5	29	22	45	51	13	4
ABF6	56	42	46	30	6	8
ABF7	16	13	18	10	5	3

STF3) and low variability in most of the cultivated sites (CF1, ABF2, ABF4, ABF7 and CRF). STF2 exhibited very low variability in SOC values because it is a short-term fallow with very little diversity in vegetation.

The high variability found in ABF1, ABF3, CF2 and ABF6 could be related to microtopography and age of the surface within which the site occurred. ABF1 is characterized by a high degree of microrelief variability (see chapter 5) while ABF6 is very young and active, with processes of erosion and deposition occurring within the site. Similar explanation can be offered for the variability in ECEC and total N, since they are related to SOC. As indicated earlier, base saturation was related to Harmattan dust influx from the Sahara desert. The dust is deposited on the soil surface every year during the long dry season. An even annual deposition of the base rich particles is the most probable explanation for the low variability in base saturation and pH values recorded in this study.

6.2.9 Correlations among the dynamic indicators of soil quality

Two groups of biochemical properties can be identified, based on their relationship with soil depth: those properties with significant surface concentration (SOC, total N and ECEC) and those with a more even distribution with depth in the profile (total P, Base Saturation, pH and EC). The former group is inherently more susceptible to loss of surface soil.

The three properties with a significant surface concentration are highly correlated (Table 6.12). SOC is the dominant property in this group insofar as total N occurs in a relatively constant ratio to C and the organic material provides the majority of the exchange sites in these sand-dominated soils. Of the three properties only SOC and ECEC show moderate and significant correlations with the ^{137}Cs levels measured at all non-reference sites. The coefficient of determination for the relationship between cesium levels and the two properties is only about 40%, indicating that a considerable amount of the variation is not explained by this relationship. The weaker correlation for total N occurs because the two sites in the concave lower slope positions (CRF and SFT2) have relatively lower amounts of N (as reflected by the higher C:N ratios).

The remaining properties examined show a greater range of correlations. Total P has a moderate correlation with ECEC (r^2=36%) but is not significantly related to either % base saturation or pH. Given the high site-to-site variation in total P observed and the lack of a clear explanation for the observed pattern this trend should be expected.

Percent base saturation shows a strong, inverse correlation to pH that runs counter to expectations for this relationship. The inverse relationship occurs primarily due to the lower slope soils – the four soils all have relatively low pH values (for the study region) and % base saturation levels over 90%. The significance of the relationship for soil quality is unlikely to be great given the small (and generally favorable) range of pH values that occurs at all sites. The influence of the four lower slope soils is also strong for the moderate correlation between % base saturation and ^{137}Cs.

Table 6.12 Pearson correlation coefficients and significance level (in italics) for the dynamic soil properties. Correlations are calculated for the mean value from each individual site (N=16, depth = 0-10 cm).

	SOC	TN	TP	ECEC	BS	pH
TN	.89					
	.000					
TP	.35	.31				
	.18	*.24*				
ECEC	.86	.69	.59			
	.000	*.003*	*.017*			
BS	.30	.00	-.04	.43		
	.25	*.99*	*.88*	*.100*		
pH	.13	.46	.35	.06	-.68	
	.62	*.07*	*.18*	*.82*	*.004*	
Cs-137[1]	.62	.43	.49	.68	.64	-.27
	.019	*.13*	*.07*	*.008*	*.013*	*.36*

1: The cesium values for the two reference sites are not included in the correlations for these properties.

The trends observed for total P and soil pH confirmed the observation that these properties were insensitive to erosion. Phosphorus is expected to be sensitive to soil redistribution and plant uptake since it is derived from minerals present in the parent material, with no appreciable cycling through the atmosphere. However, for erosion to be effective in redistributing P, the P must be concentrated in the surface horizon (Anderson and Gregorich, 1985). As was seen in Figure 6.5, total P was more evenly distributed in the first three layers of the reference site compared to SOC and Total N.

6.3 Dynamic soil properties and vegetation regeneration at the fallow sites

There were five fallow sites in the study: two long-term fallows and three short-term fallows. LTF1 and LTF2 were the long-term fallows of 50 and 20 years respectively. STF1, STF2, and STF3 were the short-term fallows of 4, 5 and 1 years, respectively. Vegetation regrowth depends on soil conditions, frequency and intensity of disturbance, and on the type of associated vegetation (Ahn, 1959; Juo and Manu, 1996). Correctly interpreted, regrowth vegetation throws considerable light on soil conditions. The older the regrowth, the closer the organic matter content of the topsoil will approach the original level, while the rate of regrowth vegetation serves to suggest the general level of fertility of the soil (Solbrig et al., 1996). The age of regrowth vegetation can therefore be expected to indicate the extent to which this has taken place. This section therefore, describes the vegetation conditions of the fallow sites studied compared to the uncultivated site.

6.3.1 Plant life-form and species encountered

Quality and quantity of vegetation decreased from the uncultivated site to the recently fallow sites (Table 6.13 and Appendix B). UC had the highest species diversity and quantity. A total of 10 woody plants/shrub species, 18 herb species and 8 individual grass species were encountered in this site. The dominant woody species were *Acacia goumensis* with a relative density of 22% followed closely by *Pterocapus eri* and *Butyrospermum* with relative densities of 17% each. *Borreria scaba* and *Hibiscus vitifolus* were the dominant herbs encountered.

Table 6.13 Vegetation status of the uncultivated and fallow sites

	Life-form			
	Woody/shrub trees			
Site	***Total # of Individuals (N)***	***Total # of Species (S)***	***Density (# of plants per unit area (m^2)***	***Relative density (%)***
UC	35	10	1.92	11
LTF1	31	9	1.53	16
LTF2	8	6	0.8	5
STF1	4	4	0.4	2
STF2	0	0	0	0
STF3	0	0	0	0
	Herbs			
UC	112	18	6.2	36
LTF1	21	5	1.1	11
LTF2	66	5	8.4	43
STF1	56	4	5.6	33
STF2	34	10	6.4	35
STF3	32	3	5.4	28
	Grasses			
UC	165	8	9.14	53
LTF1	142	6	7.1	73
LTF2	80	4	8.0	52
STF1	110	4	11	65
STF2	62	4	12.4	65
STF3	82	4	16.4	72

The dominant grass species included *Heteropogon contortus*, *Andropogon gayanus*, *Rottboelia exaltata* and *Seteria*.

LTF1, the 50 year fallow site, had the next highest number of woody and shrub species. The form, structure and diversity were, however, poorer than the uncultivated site; shorter and more open species were predominant at this site. The vegetation consisted of mixed grasses and shrubs interspersed with economic trees. The species diversity was also changed. The total number of species was lower than UC and several new species (i.e. species not found at UC) were also encountered. Only six different herb species occurred in this site compared to 18 herb species that occurred in the uncultivated site. Of the 6 herb species only two species (*Indigofera pulchra* and

Tephrosia eleganse) are common to the two sites. As well, the overall density of herbs was markedly lower at LTF1 than UC. Of the grasses, *Cybopogon gigantus* and *Eragrostis curvulus* were the new species encountered.

The vegetation at LTF2 was poorer than LTF1. The woody trees and shrubs present are a close subset of those found at UC – five out of the six species found at LTF2 are also found at UC. Herbs again show a major decrease relative to UC – only four species are present at LTF2 and two of these species (*Borreria scabra and Tephrosia eleganese*) comprise over 90% of the total herb cover.

Vegetation at the younger fallows (STF1, STF2, STF3) consisted of mixed grasses and shrubs interspersed with economic trees similar to those found at LTF2 but frequency and diversity were much lower. Generally, the number of herb species decreased from STF2 (5-year fallow) to STF1 (one-year fallow). All three have a higher density of grasses than the long-term fallow or the UC site.

The quantity and quality of vegetation encountered at the study sites seemed to be related to dynamic soil conditions, as well as the frequency and intensity of disturbance (Chapter 5). UC has never been cultivated and represents the native vegetation; it had the greatest plant diversity and frequency. From the soil analysis, this site had the highest amount of SOC and total N. The low level of vegetation recovery in LTF1 and LFT2 is also consistent with soil analysis results. For example, at LTF1, a site that had been in fallow for 50 years, the level of SOC was just about 50 % of what was observed in UC. After 15 years of fallow, vegetation and nutrient regeneration is expected to reach about 80% of the equilibrium value (Sanchez, 1976; Jaiyeoba, 1997). This slow rate of recovery at LTF1 could be attributed to length of cultivation and the succession vegetation species. Even though about 35% of the woody species sampled occurred in LTF1, the type of trees found here were shorter and scattered, and there are very few herbs. The grasses encountered are those found on very poor soil (Innes, 1977). The absence of herbs, however, could be attributed to the high degree of fires suffered by this site (personal communication, village chief).

The results, therefore, confirm that the history of previous cultivation is as important as the history of fallow because land that had been cultivated to near-exhaustion takes much longer to recover ((Ahn, 1959; Nye and Greenland, 1964). Plant nutrients and organic matter in many tropical soils, other than hydromorphic soils and those developed on highly basic parent materials, are concentrated in the immediate surface (Greenland, 1973; 1975). Consequently, the loss of topsoil may result in a reduction in fertility that can recover only if the soil is left under natural vegetation for periods perhaps as longer than 50 years. Because of the inevitable loss of mineral nutrients during the cropping phase, recovery of the total nutrient stock in the cultivated system is expected to be progressively slower than that of the natural ecosystem. An extended cropping period usually has more severe consequences than a shorter fallow as the seeds, stumps, and roots from which fallow vegetation normally regenerated when the land is abandoned die or are killed. As a result, the natural soil cover re-establishes slowly, and erosion may delay or prevent the rebuilding of soil fertility.

The vegetation status of STF2 could, however, be related to the age of fallow and the landscape position. STF2 had high organic matter and total nitrogen but does not have any trees; probably because of the short fallow period this site had been exposed to before sampling. According to Innes (1977), moist lowlands support their own characteristic variants of savanna vegetation. Towards the base of long slopes, where impermeable layers of groundwater laterites deflect internal drainage water to the surface, the upland species begin to disappear and finally give way to marshy or swampy bottomland tree savanna or open grassland.

The soil and vegetation depend on each other for sustainance. Vegetation depends on soil nutrients for growth and development, in the same token, soil conditions depend on vegetation characteristics for their replenishment (Solbrig et al., 1996). Inherent soil fertility and length of fallow are some of the important factors that affect nutrient accumulation under fallow. Plant species vary in their efficiency to accumulate different mineral nutrients. Inherent soil fertility is very important because it is the primary source of nutrients for vegetation growth. Studies have shown that the availability of resources (light, water, and nutrients) determine the amount of biomass that may be produced in a given environment. Of these three resources, plant-available moisture and plant-available nutrients may be the most limiting factors in the semiarid tropics (Solbrig et al., 1996). Topography, fire, animal and human activities modify these two factors to determine the density of the tree layer, the productivity of the system, and the rates of nutrient and water flow through the system (Solbrig et al., 1996; Medina, 1996).

6.4 Summary of dynamic properties

The study supports the applicability of the ^{137}Cs method for erosion research in the study area. Appreciable amounts of ^{137}Cs were measured in the soils of the study sites. Profile distribution had a sharp decline with depth. The amount of ^{137}Cs measured in the cultivated fields indicated that most of the sites had lost Cs. The degree of loss was related to landscape position and farming practice. The highest losses occurred in the upper/mid slope compound farms. In the bush farms the losses were not large - only two out of five bush farms experience significant losses.

On the lower slope Varempere soils, the changes in ^{137}Cs were also not significant. Two sites within this landscape position gained small amounts of ^{137} Cs, two sites lost small amounts. The results indicate that overall the bush farms are not leading to high erosion losses; however, the soil being removed from the upper slope fields is not being deposited within the landscape as indicated by the very slight gain in ^{137}Cs observed in the lower slope positions. The ^{137}Cs values obtained for CRF (on the lower slope of the highly eroded CF1 land surface) is a strong indication of this phenomenon. The only site that had a pronounced level of deposition is ABF6 within the Kugri hill catchment area. The result confirmed the description of this is a depositional area within an actively eroding landscape.

Organic carbon content of the soil fines also indicated losses of SOC from the cultivated sites. The highest levels of SOC were recorded in the uncultivated site (UC). The long term fallow (LTF1) had much lower than expected SOC content compared to recovery rate is has been slow. The SOC levels of the compound farms were also low, but the level seemed to be related to the socio-economic condition of the farmers using the sites. CF1, which belonged to the chief of the village, had higher amount of SOC than CF2, which belonged to a poorer family.

There was a clear relationship between the distribution of SOC and landscape position. The cultivated sites on the lower slope had higher SOC than those on upper slope positions. The SOC values provided a clear distinction between those sites that are lower parts of the continuous slope (ABF2 and ABF4) and those that were in concavities at the base of the slope (CRF and STF2). ABF2 and ABF4 had very low values compared to CRF and STF2. The SOC content of ABF6 also confirmed the description of this site as depositional. Total N and ECEC were closely related to SOC. There were indication of possible losses within the wetter CRF and STF2 sites because of the high C:N ratios recorded for these sites despite an overall higher SOC.

Total P was generally low and there was no clear relationship between sites and the other major soil properties - for example the total P measured in UC was much lower than LTF1. Lowest P values were measured in ABF2 and ABF3 as well as ABF7. Also there was no relationship between P and Cs-137 redistribution. Base saturation and pH also had no relationship with site cultivation status and erosion. The values measured were higher than expected for the soil type, but they are consistent with other results from the region. The high values are related to annual dust influx related to the Harmattan winds.

The plant species found on the uncultivated site are much more diverse than those at the fallow sites. The vegetation status of the fallow sites was related to years of fallow. The longer the fallow period, the greater the quantity and diversity of plant species.

7. GENERAL DISCUSSION

The research was carried out with the overall objective of evaluating the effect of farming practices on soil quality. To achieve this general objective, a systems approach that combined the analysis of soil properties under different farming practices with a socio-economic survey of farmers' circumstances was adopted. The specific objectives, therefore, were to identify soil properties that can be used as indicators of soil quality, measure soil erosion and its impact on the selected indicators of soil quality and finally, understand the farmers' socio-economic conditions that affect land use decisions.

The major farming systems of Northeastern Ghana were studied using sixteen farmers' fields within the dominant soil association found in the region. The sites were stratified according to farming practice and slope position. Farmers' fields and practices were used to ensure that the most commonly used local farming practices were studied and that the results represent the practical situations that the farmers face in the fields. Stratifying sites according to slope position made it possible to differentiate between effects related to geomorphology and those due to management. The geomorphology of the region indicates that the area had undergone a number of erosion cycles that produced a set of complex landforms. The upland soils were older and concretionary while the lowlands were occupied by younger, deeper and less concretionary soils. To study the social and economic conditions that affect farmers' land use decisions in the region, both formal and informal interviews were conducted. The informal interview and government reports provided the background information and the formal questionnaire interview of 180 households provided information on specific issues relating to the farming system.

7.1. Current state of the soil under the different farming practices

Most of the cultivated sites studied were degraded or at risk of degradation compared to the system under native vegetation. Soil degradation, which refers to decline in soil quality, is defined here as the decline in the productive capacity of the soil (Larson and Pierce, 1994). A decline in the productive capacity of the soil refers to adverse changes in nutrient status, soil organic matter, structural attributes and concentrations of electrolytes and toxic chemicals as a result of one or more degradation processes. In this study, the approach used to assess the quality of soil was essentially quantitative; however, the socio-economic survey indicate that farmers have their own qualitative approach to soil quality assessment.

7.1.1 Soil redistribution

The use of ^{137}Cs to assess soil redistribution proved to be effective in this study. The use of ^{137}Cs in this region has been limited due to lack of gamma spectroscopy instrumentation as well as concerns about the base level of ^{137}Cs in the reference sites in this latitudinal belt. The results of this study and the other studies cited previously from this latitudinal belt clearly indicate that the concerns about the reference inventory are misplaced.

A second concern about the use of the ^{137}Cs technique relates to its variability in reference sites. The variability at the two reference sites (i.e., CV's of 24% (UC) and 27% (LTF1) are comparable to those found in more temperate regions. In an extensive literature review of ^{137}Cs variability for reference sites in over 70 published studies, Sutherland (1996) found a range of CV's from 1 to 86%, with a median CV of 19%. At 13 reference sites in New Zealand, Basher (1998) found a range of CV's from 7 to 45 percent, but with a median value of 17%. Hence the variability found at the two reference sites in this study are comparable to other published sources.

Based on the use of the ^{137}Cs technique, erosion was observed to be an important, but not dominant, contributor to changes in soil properties. It is expected that the high erodibility of the sandy soils and the pressure on land in this region would lead to high erosion rates. The measured soil losses clearly showed the influence of both slope position and management. Rates of soil loss ranged from a mean of 19 Mg ha^{-1} yr^{-1} for the two compound farms on the upper slope positions, 7 Mg ha^{-1} yr^{-1} for the upper slope bush farms, and negligible soil redistribution values for the lower slope sites.

The erosion rates obtained in this study are within the range suggested for the region (Lal, 1995). There is only a little discrepancy between Lal's results and those of the present study, which suggest that his estimates have not unduly suffered from the use of relatively short-term studies. However, it is likely that both his estimates and those from the present study do not account sufficiently for spatial variation in soil redistribution and so may not be very representative of the entire sub-region.

The results, however, give cause for concern in relation to sustained productivity. The rates for the compound farms are approximately 20 times greater than the rates of soil formation and four times greater than the estimated acceptable soil loss of 5 Mg ha^{-1} yr^{-1} (Elwell, 1985). Using an erosion rate of 50-80 Mg ha^{-1} yr^{-1}, Elwell (1985) suggested that subsistence yields could be threatened within 30 years. Although the rates obtained here are considerably lower, they do suggest that subsistence yield may be threatened before the middle of the next century. This is especially true for the shallow soils encountered in this region. Lal (1995) estimated an average yield reduction of about 14.5% for Sub-Saharan Africa and 15% for the whole of Africa by the year 2020 assuming no change in land use and the current rate of soil erosion continues. Given that the present level of production is low, a further reduction would be disastrous in the face of increasing population growth.

The organic matter content of a soil and erosion are intimately linked (Lal, 1976b). Decreases in soil organic matter lead to deterioration of chemical, physical and biological properties of the soil, which may lead to increased erosion rates. For example, as soil organic C decreases, macro-aggregation decreases and soil erodibility increases. A decrease in organic matter content of the soil also increases its susceptibility to formation of surface crusts, which further enhance the risk to soil erosion (Lal, 1976a). The use of the model to estimate the SOC losses due to erosion does indicate, however, that non-erosion losses of SOC are as great or greater than the erosion-induced losses. Hence the maintenance or restoration of SOC levels in these landscapes cannot solely rely on erosion mitigation.

7.1.2 Soil properties that can be reliably used as indicators of soil quality

The approach used to evaluate the state of the soils in this study was a combination of the traditional comparative approach proposed by Larson and Pierce (1994) and indigenous technical knowledge. It is comparative in the sense that the uncultivated site was use as a benchmark site against which the cultivated sites were compared.

The soil properties investigated were inherent properties (soil horizonation, soil colour, Fe-oxide, magnetic susceptibility, soil texture, bulk density and concretion content) and dynamic soil properties (SOC, ECEC, total N, total P, base saturation, pH and EC). There was a clear distinction between inherent soil properties and the dynamic soil properties in terms of soil quality changes under the different farming practices. The next sections concentrate on the properties of greatest importance for soil quality evaluation in this region.

7.1.2.1 Depth to concretion and percent concretion

The soils are naturally concretionary, with the amount and depth to concretions varying according to landscape position. The upland sites had high concretions. Although concretion content is landscape related, it could be used as an important indicator of soil quality in the study region. Among sites on the same landscape position there were marked differences that could be related to management practices. Concretion content in excess of 40% occurred within 20 cm of the surface of sites STF1, LTF1, ABF1, CF1, STF3, and LTF2.

The importance of concretions is also reflected in the local system of soil classification and quality evaluation (Section 4.2.1.1). The Kusaasi tribe classifies a soil with low amounts of gravel/concretion as the best agricultural soil. Concretion content is important in soil quality assessment because it affects dynamic properties such as A-horizon thickness and P availability. Concretions occur at depth and form plinthites, which are brought closer to the surface as a result of erosion. Plinthite was observed at both sites LTF2 and STF3, although the possibility exists that these may pre-date the cultivation of the landscape.

Exposing and incorporating concretions into the surface soil interferes with various functions of the soil especially for upland sites. Concretions act as rock fragment or gravel to affect physical properties of soils in which they occur. Concretions by themselves, or as plinthites form an unconformity of textural change with depth, reduce soil volume, increase bulk density and reduce total porosity (Babalola and Lal, 1977; Sanchez, 1976; Eswaran et al., 1990; Cassel and Lal, 1992). Increased bulk density and soil strength leads to reduction in the volume of macropores and total porosity (Cassel and Lal, 1992) which in turn affects water and nutrient movement, plant uptake and root development (Eswaran et al., 1990). For example Babalola and Lal (1977) observed root development of maize seedlings to be adversely affected by gravels when their mass exceeds 10-20%. Unconformity of textural change with depth increases erosion hazard (Sanchez, 1976). Brakensiek and Rawls (1994) reported that rock fragments reduce infiltration and thereby increase runoff. As the topsoil erodes, more concretion-loaded subsoil is incorporated.

Concretions have chemical constraints associated with their high Fe content. Fe-oxides, hydroxides and oxyhydroxides that are the dominant minerals in concretions possess large specific surface areas, which contribute to the overall surface area and chemical nature of the soil (Schwertmann and Herbillion, 1992). These properties provide sinks for inorganic and organic anions and cations. The best known effect of Fe-oxide is its affinity towards P retention (Schwertmann and Herbillion, 1992; Mokwunye and Hammond, 1992). Tiessen et al. (1993) found that more than half of applied soluble P fertilizer was sorbed by Fe concretions in soils of Northern Ghana.

This chemical constraint may not be a problem due to the consistently high pH recorded at most of the sites. pH values ranged from 6.4 to 7.6, which is within the range noted for reduced adsorption, suggesting that P sorption of the soils is low. The tendency of Fe oxides to act as sinks for P is explained by their charge characteristics at different pH. As pH increases, the surface charge of the oxides and clays become negative and hence there is less sorption of P than when the surface is positive (Barrow, 1984). Fe and Al oxides and clay minerals adsorb P mostly under acid conditions when the surface is positive. Abekoe (1996) found that introducing pH values into a multiple regression improved the prediction of P sorption for some soil of Northern Ghana, which reinforced the importance of surface charge of the colloidal complex on P sorption. Greenland (1973) warned of the undue emphasis put on the P-fixing capacity of the soils in Africa. Reports show that West African soils have low to medium P fixing capacities (Juo and Fox, 1977; Owusu-Bennoah and Acquaye, 1989; Manu et al., 1991).

7.1.2.2. Soil organic carbon

Soil organic C was very sensitive to management. Generally SOC measurements within the study sites were relatively low compared to temperate regions. The most important observations were the low levels of SOC in the long-term fallows (LTF1 and LTF2). As discussed earlier, these sites have been in fallow for a sufficient length of time for regeneration of vegetation and fertility to reach a peak. Also, the importance of socio-economic conditions of the farmer in soil quality maintenance was evident (for example, in the comparison of SOC levels at CF1 to those at CF2). The richer farmer at CF1 had more cattle and was able to maintain relatively higher organic matter levels on his farm using the droppings from his livestock.

Soil organic carbon was generally low and concentrated in the surface of the soil. About 64% of the total SOC was concentrated in the surface 0-20 cm layer of surface soil, which is typical of tropical soils. For instance, Garcia-Oliva et al. (1995) found that 51% of the SOM, 40% of soil potassium, 54% of the available phosphorus, and 53% of the total N were in the 4-cm surface layer of the deciduous forest soils they examined. This implies that most of the essential nutrients are concentrated in the top few centimeters of soil. A loss of the surface organic material has a negative impact on productivity of the soils.

Both the upper slope compound farms and bush farms recorded high losses in organic matter and soil N compared to the uncultivated site. Most of the sites had lost more than half their original SOC. SOC was highly positively correlated to total N and ECEC. SOC is the store for soil N and charge in these sandy soils, and hence the high correlation between these three properties was expected.

The contribution of SOC to soil productivity is very important and well understood. SOC is a major natural source of nutrients for plant growth especially in agricultural systems that do not rely on fertilizer inputs. The chemical and physical interactions of SOC with soil minerals improve structural characteristics of the soil. SOC also makes significant contributions to variable charge in tropical soils with low activity clays (Tiessen et al., 1994). Biological properties of the soil are also influenced by the store of organic matter in the soil.

An appreciable part of the observed losses in SOC are believed not to be related to erosion. Cultivation increases the rate of nutrient cycling, which affects other soil processes such as SOC storage and structure (Warkentin, 1995). The labile pool of SOM, which is directly related to soil productivity, is the first component to be reduced (Hsieh, 1996). These changes in the relative pool distribution of SOC are accompanied by a decrease in the activity of enzymes involved in C, N and P cycling (Schulten et al., 1995). In tropical soils, the effect of cultivation is severe because both labile and stable SOC pools are subject to higher rates of decomposition than those of temperate soils (Hsieh, 1996). The result is a reduction in the nutrient supply for crop growth, the size of microbial biomass and C storage, all of which reduce soil quality (Schulten et al., 1995).

The fallowing system used in this region was not successful in maintaining SOC levels. Recovery of SOC during the fallow phase depends on the rate of SOC build up, which in turn depends on vegetation regrowth during fallow periods. Vegetation regrowth is related to the state of the soil at the time of fallow as well as disturbances during the fallow phase such as the frequent bush fires that had affected site LTF1. This site had been in fallow for about 50 years or more. It was expected to have recovered a substantial amount of its nutrients, but the actual recovery was limited.

From an ecosystem perspective, the main function of the fallow phase is essentially the transfer of mineral nutrients from the soil into vegetation biomass. Because of the inevitable loss of mineral nutrients during the cropping phase, the total nutrient stock in the entire ecosystem during the incremental fallow cycles becomes progressively smaller than that of the original ecosystem. The total amount of biomass in the secondary vegetation may take hundreds of years to reach the levels comparable to the primary vegetation due to repeated cycles of slash and burn cultivation.

7.1.2 Soil properties of limited value as indicators of soil quality

The observed differences in the inherent properties such as soil colour, texture, and bulk density were related to slope position and drainage conditions rather than management practices. Although they played an important role in the establishment of similar pedological-slope units in the study area, they are of limited value in soil quality evaluation.

Fe-oxide content and magnetic susceptibility were also related to landscape position. The magnetic susceptibility measurements could be used as an independent source to confirm the ^{137}Cs results insofar as both techniques indicated a lack of deposition of sediment derived from the upper slopes in the lower slope positions. As well, the magnetic susceptibility results indicate that they are useful as an indicator of imperfectly to poorly drained soils in pedological studies.

EC, pH, and base saturation did not show any marked differences between management practices. The high pH and base saturation values are probably due to the yearly dust influx associated with the long dry Harmattan season. This suggestion is reinforced by the insensitivity of these properties to erosion as was observed in this study. The apparent insensitivity to erosion could be related to thier even distribution within the first three sampling depths. Even though pH values were not sensitive to management, the assessment of pH is very important for the chemical processes that occur in the soil, especially for P dynamics.

7.2 Potential for changing the land management system

The management system can only be successfully changed within the socio-economic conditions of the farmers. The region is characterized by a lack of financial resources, social services, and land resources. Agricultural production is on a subsistence basis, which does not provide enough income to support all the financial obligations of the farmers or collateral for bank loans. Livestock is an important financial resource in times of financial stress. Poor marketing systems and storage facilities also weaken the financial situation of the farmers. In times of bumper harvests farmers do not have good storage facilities to store their produce for a better price. The traditional storage barns are either too small to contain large quantities or are heavily infested with storage pests. Farmers are often at the mercy of middlemen who dictate the produce price. This is a major disincentive for increasing production.

The lack of electricity or other sources of energy for cooking encourages deforestation with consequences of accelerated land and environmental degradation (Nsiah-Gyabaah, 1996). Electricity is only supplied to the regional and district capitals. The villages depend on kerosene lamps and firewood for light and fuel, respectively. Lack of electricity also discourages rural agro-industries, which is one major factor responsible for rural-to-urban migration. Most of the able-bodied young men travel down south to work in the cocoa farms and mines, leaving the women, children and old men behind as was seen in the population structure of the region. As a consequence, land management and soil conservation suffer because the people left behind are often not able to undertake conservation practices that are labour demanding.

Formal education level is one of the lowest in the country. In this study, only 25% of the respondents had any form of formal education. This 25% is mainly the younger respondents. The significant relationship between age and education is a hope for the future, because the more highly educated members of the population are most likely to adopt conservation measures. Also, with more education, the number of wives and children per male was lower.

Population of the region is increasing at the alarming rate of 3.2% per annum (Statistical Services Department, 1984). Between the years 1960 and 1984 the population of the region almost doubled without a corresponding increase in available resources and services. This increase in population puts pressure on the available resources such as land holdings. This was indicated by a majority of respondents, who cited land pressure as a major reason for reduced fallow and increased cultivation cycles. Other consequences of population pressure were increased fragmentation of land and the increased distance farmers have to travel to acquire farmland. Apart from the burden of long travel, migrant farmers tend to bring with them cultivation practices that may not be sustainable in their new farming area (Wangia and Prato, 1994). Also migrant farmers tend to be less committed to the land they are farming (Hudson, 1986; Saul, 1988).

Land resources are limited due to increasing population pressure. Land is communally owned and allocation is through the spiritual leader or family head. This system of land tenure is associated with an insecurity of tenure and land fragmentation. Insecurity of tenure discourages private investment in soil conservation in the following manner. First, the farmer is not committed to the land. Second, without legal tenure farmlands cannot be used for collateral to raise bank loan to improve the soil (Nsiah-Gyabaah, 1996). Land fragmentation associated with the communal system of land ownership also makes it difficult to implement soil conservation projects, because most national conservation programs are more economical and practicable on large parcels of land (Wangia and Prato, 1994).

The land tenure system appears to be one of the explanations for the attitude of farmers to resource use, conservation and long-term land improvement in the region. To motivate farmers to control soil erosion on their farms and to adopt sustainable practices, security of tenure must be assured. Land title registry may be important legislation; however, this may be difficult since a majority of the farmers were satisfied with the current system. In my view, enforcing land title may exacerbate the problem in several ways. For example, private ownership may lead to land purchase by the urban rich, who may not be committed to land resource conservation. These urban rich may not be committed to farming and they will either rent out the land to the rural poor or use them as hired labour to farm on these lands. This will lead to commoditization of the rural poor as a labour force on these lands.

Local agricultural support services currently offered to farmers include training and demonstration of improved practices, input supply and veterinary services and loan arrangements. The type of training offered is, however, limited to agronomic practices such as planting in rows and fertilizer application and the use of improved seeds. Soil conservation practices are not emphasized in these packages. In most developing countries, input supply is an important function because of the financial situation of the farmers (Douglas, 1990). Inputs are most often supplied on credit and payment is made in kind with agricultural produce. However, as part of the Structural Adjustment Program (SAP) initiated in 1989 with the assistance of the World Bank, fertilizer subsidies have been removed and sale of fertilizer had been privatized. As a result, fertilizer prices have increased, leading to a decline in its use. Farmers no longer use fertilizers in the required quantity.

7.3 Recommendations for the future

7.3.1 Research needs

The need to introduce more improved systems of land management cannot be over emphasized. Agronomic soil conservation methods such as crop rotation with leguminous species, intercropping with legumes, cover cropping, composting, green-manuring and, more recently, agroforestry are available. The beneficial effects of these practices have been well demonstrated on research farms but their adoption has not been very fast. Conditions on research stations are often very different from farmer's fields. Most research stations occupy the best farmlands and the basic infrastructure is available for agricultural operations.

There is the need for more basic research into those practices that focus on the underlying biophysical and socioeconomic process at landscape-scale on farmer's fields. For example, indigenous trees for agroforestry and the interaction between these tree species and food crops need to be studied. For example, in the study area the shear butter tree is one of the common tree specie found on farmer's fields. Improvement of the fallow system through the use of indigenous leguminous fallow species is another area of research.

Correlation of indigenous technical knowledge with scientific studies is also required. This would go a long way to reduce the cost of future research, as field work could be reduced if farmers' knowledge become a trusted source of information.

7.3.2 Development needs

Substantial indigenous technical knowledge exists. The local people are aware of their environment, their production risk and land degradation. They know that their land is degrading in quality and they seemed to have a positive commitment to resource conservation. However, they are limited by their socioeconomic conditions. It is often argued that poverty and resource base abuses have been caused largely by policies of the state and the global economy. Therefore, the interrelated socioeconomic, ecological, political, and historical factors with both internal and external dimensions that account for the environmental degradation must also be dealt with. In addition to the landscape-scale research, the quality of life of the rural people must be improved.

Insecure land tenure is an important barrier to development and as a contributory factor to ecological degradation (Bonsu, 1981; Hudson, 1981; FAO, 1985; Wangia and Prato, 1994). Insecurity of tenure discourages private investment in resource conservation. Since the farmers do not hold legal tenure over the farmlands they have no collateral to raise a bank loan to improve the soil. Land that is communally owned is often abused. Firewood for example is harvested without due consideration to the harm that the individual's collecting habits have on the local environment. Apart from the insecurity of tenure, land fragmentation associated with traditional tenure is yet another major constraint to soil conservation because major soil conservation programs are difficult to implement on small parcels of land (Wangia and Prato, 1994).

The most widely recommended solution to security of tenure is land title registration, which may not be feasible in the study area. An alternative to land title registry is to look into ways of making soil conservation practices part of the farming system. The local extension agents could be strengthened through training so that they can mount education campaigns on soil conservation. The focus group should be the village chief, his elders and the spiritual leader. I believe that once the spiritual leader and the chief and elders are part of the development process, they will be committed. Soil conservation implementation could be made a condition for land allocation. This will be monitored and violation should lead to possible land confiscation or other appropriate sanction.

Other, more general development needs for this region are:

1) National policies directed at poverty alleviation in rural areas should be vigorously pursued. To improve the quality of life of the local people ,basic infrastructure such as good water supply, health-care, electricity, roads and schools should be provided. A national rural electrification program has also been initiated, with the target of supplying electricity to all rural areas by the year 2020. Electric supply will encourage the development of agro-industries and commercial centers. With improved quality of life, the younger generation will be attracted to remain in the rural areas.

2) Improved transportation and storage systems are also very important for improving the quality of life in rural areas. Access to market and other commercial centers rely heavily on a transportation network. With limited access to market, farmers will not be motivated to adopt conservation methods aimed at increasing productivity.

3) Improving the level of formal education by encouraging greater enrollment and school attendance. Adult education programs should be an important component of

the literacy program. Linked with education is the formation of farmer cooperatives. As a group, much more can be achieved, for instance, better access to credit and marketing.

4) The current extension services appears to be adequate in their numbers and farmer contact, but it is lacking in the information they provide in terms of soil conservation. There is a need to train the extension services personnel so that they can provide the support needed.

5) The use of natural gas and solar energy for fuel could solve the problem of deforestation associated with fuel wood collection and charcoal burning. The introduction of gas stoves into all rural areas, initiated in 1990 by the Energy Board, should be reviewed and more vigorously pursued. Availability of natural gas in all parts of the country is very important for the sustainability of the program. Currently, natural gas is only available in bigger commercial centers, which does not provide enough incentive to the rural dweller to switch to natural gas as an alternative source of household fuel. Solar energy can be a very cheap alternate source of fuel. This source is yet to be tapped, probably because of lack of research and development.

6) Special effort should be made to assist women because the women are at a greater disadvantage in this society. Women are involved in all aspects of community life; housekeeping and farming, food processing and transportation of farm produce to the house and to the market and commerce. They are the least educated members of the population; land and labour are not easily available to them. They have very limited resources to generate income, which is very much needed.

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APPENDIX A

SITE AND PROFILE DESCRIPTION (1996 sites)

UC1: Uncultivated site

Never been cultivated. Vegetation is dense tree cover and undergrowth of grass, shrubs and vines. It is on a mid slope position. Soil is generally very deep, dark, and loamy.

UC- C2 Close to ant hills (same as main pit)

0-7 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, very fine fine granular, soft, friable and non plastic. Few concretions.
7-13cm A_2	5 YR 2/2 brown black sandy loam with gravels. Weak to moderately strong, fine and medium single grain. Slightly hard, friable to firm, and slightly plastic. Many concretions.
13-30 cm ABc	5 YR 2/2 brown black fine sandy loam with gravels. Weak to moderately strong, fine and medium single grain. Slightly hard, friable to firm, and slightly plastic. Abundant concretions.
30-62 cm B_1c	5 YR 5/3 dull red brown fine sandy loam with gravels. Moderately strong coarse sub-angular blocky, hard, firm and plastic. Concretions abundant.
62-128 cm B_2cx	Cemented and massive.(Concretions dominant with fragipan character)

UC- C3 (close to ant hills)

0-11 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, very fine, fine granular, loose, very friable and non plastic. Few concretions.
11-24 cm A_2	5 YR 2/2 brown black sandy loam few gravels. Moderately strong, fine and medium sub-angular, slightly hard, firm and slightly plastic. Concretions many.
24-32 cm ABtc	5 YR 5/3 dull red brown sandy clay loam abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions abundant
32-61 cm Bcx	Massive and dominantly concretions

UC- C4

0-7 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, fine and medium granular, loose, very friable and non plastic. Concretions common.
7-16 cm A_2c	7.5 YR 2/2 brown black sandy loam few gravels. Weak to moderately strong, fine and medium sub-angular blocky. Slightly hard, firm and slightly plastic. Concretions many.
16-33 cm ABtc	7.5 YR 3/3 brown black sandy loam with clearly distinct orange mottle (7.5 YR 7/6) and abundant gravels. Moderately strong, fine and medium angular blocky, hard, firm and plastic. Concretions many.
33-48 cm B_1tc	7.5 YR 3/3 brown black sandy clay loam with clearly distinct orange mottle (7.5 YR 7/6) and abundant gravels. Moderately strong, fine and medium angular blocky, very hard,very firm and plastic. Concretions abundant
48-70 cm B_2cx	10 YR 6/6 massive with mottles. Concretions dominant

UC- D2

0-7 cm Ah	10 YR 3/1 dark brown fine sandy loam, no gravel. Weak, very fine fine granular, loose, very friable and non plastic. Few concretions.
7-15 cm A_2	10 YR 3/3 dark brown fine sandy loam no gravels. Moderately strong, fine and coarse granular, loose, very friable and non plastic. Concretions common.
15-25 cm ABtc	10 YR 5/4 dull gray brown sandy clay loam with gravels. Weak, fine and coarse single grain, loose, very friable and non plastic. Concretions many.
25-34 cm B_1tc	10 YR 6/6 bright yellow brown sandy clay loam with gravels. Weak, fine and coarse single grain, slightly hard, firm and slightly plastic. Concretions abundant.
62-128 cm B_2cx	Massive. Concretions dominant

UC- D3

0-8 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, fine and medium granular, loose, very friable and non plastic. Few concretions.
8-17 cm A_2c	7.5 YR 2/2 brown black sandy clay loam few gravels. Moderately strong, coarse sub-angular blocky, slightly hard, firm and slightly plastic. Concretions few.
17-24 cm B_1tc	7.5 YR 3/3 dark brown sandy clay loam abundant gravels. Moderately strong, coarse sub-angular blocky hard, firm and plastic. Concretions common
24-45 cm B_2c	7.5 YR 3/3 dark brown sandy clay loam abundant gravels. Moderately strong, coarse sub-angular blocky hard, firm and plastic. Many concretions.

UC- D4

0-7 cm Ah	10 YR 2/1 black sandy loam, no gravel. Weak, fine and very fine granular, loose, very friable and non plastic. Few Concretions.
7-24 cm A_2c	10 YR 2/2 brown black sandy loam few gravels. Weak to moderately strong, fine and medium sub-angular blocky, slightly hard, firm and slightly plastic. Few concretions
24-35 cm ABtc	10 YR 3/4 dark brown sandy loam with clearly distinct orange mottle (7.5 YR 7/6) and abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions common
35-47 cm B_1tc	10 YR 3/3 brown black sandy clay loam with clearly distinct orange mottle (7.5 YR 6/8) and abundant gravels. Moderately strong, fine and medium sub-angular blocky, very hard,very firm and plastic .Concretions many.
47-65 cm B_2c	10 YR 3/3 brown black sandy clay loam with clearly distinct orange mottle (7.5 YR 6/8) and abundant gravels. Moderately strong, fine and medium sub-angular blocky, very hard,very firm and plastic Concretions abundant.

UC- E2

0-6 cm Ah	10 YR 2/2 brown black sandy loam, no gravel. Weak, fine medium and coarse granular, loose, very friable and non plastic. Concretions common.
6-17 cm ABc	10 YR 3/4 dark brown sandy clay loam no gravels. Moderately strong, fine and coarse sub-angular blocky, slightly hard, firm and slightly plastic Concretions many.
17-24 cm Btc	10 YR 5/6 yellow brown sandy clay loam with gravels. Moderately strong fine and medium sub-angular blocky, loose, very friable and non plastic. concretions abundant
25-65 cm Bcx	Massive. Concretions dominant

UC- E3

0-7 cm Ah	5 YR 2/1 brown black fine sandy loam, few gravel. Weak, very fine, fine granular, loose, very friable and non plastic. Concretions common.
7-13 cm A_2c	5 YR 2/2 brown black sandy loam few gravels. Moderately strong, fine and medium sub-angular, slightly hard, firm and slightly plastic. Concretions many.
13-19 cm B_1tc	5 YR 5/3 dull red brown sandy clay loam with clearly distinct orange mottle (7.5 YR 7/6) and abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions many.
19-65 cm B_2c	5 YR 5/3 dull red brown sandy clay loam with clearly distinct orange mottle (7.5 YR 7/6) and abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions abundant .

UC- E4

0-7 cm Ah	5 YR 2/1 brown black sandy loam, no gravel. Weak, fine and very fine granular, loose, very friable and non plastic. Few Concretions.
7-13 cm A_2c	5 YR 2/2 brown black fine sandy loam few gravels. Weak, fine and medium granular, slightly hard, firm and slightly plastic. Concretions few
13-19 cm B_1t	5 YR 3/4 dark red brown sandy clay loam with clearly distinct bright yellow brown mottle (2.5 YR 5/6) and abundant gravels. Weak, medium and coarse granular, hard, firm and plastic. Concretions few
19-45 cm B_2c	5 YR 3/4 dark red brown sandy clay loam with clearly distinct bright yellow brown mottle (2.5 YR 5/6) and abundant gravels. Weak, medium and coarse granular, hard, firm and plastic. Concretions many.

UC- F2

0-7 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, very fine fine granular, loose, very friable and non plastic. Concretions common.

7-17 cm ABc	5 YR 2/2 brown black sandy loam no gravels. Weak fine and medium granular, slightly hard, firm and slightly plastic. Concretions abundant.
17-24 cm B_1tc	5 YR 3/2 dull red brown sandy clay loam no gravels. Moderately strong, medium and coarse sub-angular blocky, hard, firm and plastic Concretions abundant.
24-35 cm B_1tc	5 YR 4/6 red brown sandy clay. Moderately strong, medium and coarse sub-angular blocky, hard, firm and plastic. Concretions abundant.
35-62 c B_2cx	Massive and dominantly concretions.

UC- F3

0-8 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, fine and medium granular with pores and roots. Consistence is loose, very friable and non plastic when dry, moist and wet respectively. Very few Concretions.
8-19 cm A_2	7.5 YR 2/2 brown black sandy loam few gravels. Moderately strong, coarse sub-angular, slightly hard, firm and slightly plastic. Few Concretions.
19-32 cm B_1tc	7.5 YR 3/3 brown black sandy clay loam with clearly distinct orange mottle (7.5 YR 7/6) and gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions common.
32-65 cm B_2tc	7.5 YR 3/3 brown black sandy clay loam with clearly distinct orange mottle (10 YR 6/6) and gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions common

UC- F4 (0-18 free, 18-61 Fe concretion and massive)

0-6 cm Ah	5 YR 2/1 brown black fine sandy loam, no gravel. Weak, fine and medium granular, loose, very friable and non plastic. Few concretions.
6-13 cm A_2	5 YR 2/2 brown black fine sandy loam few gravels. Weak, medium and coarse granular, slightly hard, firm and slightly plastic. Few concretions.
13-18 cm ABtc	5 YR 3/3 dark red brown fine loamy sand, few gravels. Moderately strong, coarse sub-angular blocky, slightly hard, firm and slightly plastic. Concretions common.
18-59 cm B_1t	5 YR 4/2 dull red brown sandy clay with clearly distinct bright yellow brown mottle (2.5 YR 5/6) and abundant gravels. Moderately strong, fine and medium angular blocky, very hard, very firm and plastic. Concretions abundant.
59-72 cm B_2x	Massive and concretions dominant

Long-term fallow (LTF1)

According to the chief of the village, this land has been fallowed for 50 years, hense considered uncultivated and used as a reference site.

LTF1- B2 (From 2nd horizon gravels of Fe and Mn down to iron pan under lain)

0-7 cm Ah	2.5 YR 2/2 very dark reddish brown fine sandy loam no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Few concretions.
7-18 cm ABc	2.5 YR 3/2 dark red brown fine sandy loam abundant gravels. Weak, medium and coarse granular, slightly hard, firm and slightly plastic. Concretions many.
18-38 cm B_1tc	2.5 YR 3/6 dark red brown sandy clay, abundant gravels. Moderately strong, coarse sub-angular blocky, hard, firm and plastic. Concretions abundant.
38-55 cm B_2x	Massive and concretions dominant

LTF1- B3

0-7 cm Ah	10 YR 3/2 brown black fine sandy loam no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Concretions many.
7-17 cm ABc	10 YR 3/2 dark brown coarse sandy loam abundant gravels. Weak, medium and coarse granular, slightly hard, firm and slightly plastic. Concretions many.
17-24 cm B_1tc	2.5 YR 4/6 dark red brown sandy clay loam, abundant gravels. Moderately strong,medium and coarse sub-angular blocky, hard, firm and plastic. Concretions many.
24-40 cm B_2c	2.5 YR 4/6 dark red brown sandy clay loam, abundant gravels. Moderately strong,medium and coarse sub-angular blocky, hard, firm and plastic. Concretions abundant.

LTF1- B4

0-7 cm Ah	2.5 YR 2/1 red brown sandy clay loam, few gravel. Weak, very fine and fine granular, loose, friable and non plastic. Concretions many.
7-17 cm ABc	2.5 YR 3/2 dark brown fine sandy loam abundant gravels. Weak, medium and coarse granular, slightly hard, firm and slightly plastic. Concretions many.
17-28 cm	2.5 YR 3/4 red brown loamy fine sand, abundant gravels. Moderately strong,medium and coarse

B_1c	sub-angular blocky. Slightly hard, firm and slightly plastic when dry, moist and wet respectively. Concretions many.
28-38 cm B_2c	2.5 YR 3/4 red brown loamy fine sand, abundant gravels. Moderately strong,medium and coarse sub-angular blocky. Slightly hard, firm and slightly plastic when dry, moist and wet respectively. Concretions abundant.

LTF1- B5

0-7 cm Ah	2.5 YR 2/1 red brown fine sandy loam, few gravel. Weak, very fine and fine granular, loose, friable and non plastic. Concretions common..
7-17 cm ABc	2.5 YR 2/2 very dark red brown fine sandy loam abundant gravels. Weak, medium and coarse granular, slightly hard, firm and slightly plastic. Concretions many.
17-26 cm B_1tc	2.5 YR 3/3 red brown sandy clay loam, abundant gravels. Moderately strong,fine and medium sub-angular blocky, slightly hard, firm and slightly plastic. Concretions many.
26-44 cm B_2tc	2.5 YR 4/6 red brown clay with orange mottles (7.5YR 6/8) and abundant gravels. Moderately strong,fine and medium angular blocky, hard, firm and plastic. Concretions abundant.
44-60 cm B_3x	Massive. Concretions dominant.

LTF1- C2

0-7 cm Ah	5 YR 2/2 brown black fine sandy loam, no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Many concretions.
7-16 cm ABc	5 YR 3/2 dark red brown sandy loam abundant gravels. Very weak, fine and very fine single grain, slightly loose, very friable and non plastic. Concretions many .
16-24 cm B_1tc	2.5 YR 3/4 dark red brown sandy clay loam, with bright brown mottle (7.5 YR 5/6) and abundant gravels. Weak to moderately strong,fine and medium sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant.
24-41 cmB_2x	Massive. Concretions dominant.

LTF1- C3

0-5 cm Ah	2.5 YR 2/1 red brown fine sandy loam, no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Many concretions.
5-13 cm ABc	2.5 YR 3/2 dark brown sandy loam abundant gravels. Weak, fine and medium sub-angular blocky, slightly loose, very friable and non plastic. Concretion many.
13-28 cm B_1tc	2.5 YR 4/6 red brown sandy clay loam, with abundant gravels. Strong, coarse and medium sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant.
28-42 cm B_2x	Massive. Concretions dominant.

LTF1- C4

0-7 cm Ah	2.5 YR 3/2very dark red brown fine sandy loam, no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Concretions common.
7-15 cm ABc	2.5 YR 3/2 dark brown loamy fine sand abundant gravels. Very weak, fine and very fine single grain, loose, very friable and non plastic. Concretions many.
15-43 cm B_1t	2.5 YR 4/4 dull red brown sandy clay, with abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions abundant
43-66 cm B_2x	Massive. Concretions dominant.

LTF1- C5

0-6 cm Ah	5 YR 2/2 brown black fine sandy loam, no gravel. Weak, very fine and fine granular is loose, friable and non plastic. Many concretions.
6-13 cm ABc	5 YR 3/3 dark red brown sandy loam abundant gravels. Very weak, fine and very fine granular, loose, very friable and non plastic. Concretions many.
13-41 cm B_1tc	2.5 YR 4/6 red brown sandy clay loam, with abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions abundant
41-50 cm B_2x	Massive. Concretions dominant.

LTF1- D2

0-7 cm Ah	10 YR 2/2 brown black fine sandy loam, no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Many concretions.
7-16 cm ABc	10 YR 3/3 dark brown sandy loam few gravels. Very weak, fine and very fine single grain, loose, very friable and non plastic. Concretions many.
16-38 cm B_1tc	2.5 YR 4/6 red brown sandy clay loam, with orange mottles (2.5 YR 6/8) and abundant gravels. Moderately strong, fine and medium angular blocky, hard, firm and plastic. Concretions abundant.
38-45 cm B_2x	Massive. Concretions dominant.

LTF1- D3

0-6 cm Ah	10 YR 2/2 brown black fine sandy loam, no gravel. Structure is weak, very fine and fine granular, loose, friable and non plastic. Many concretions.
6-13 cm ABc	7.5 YR 3/3 dark brown sandy loam few gravels. Very weak, fine and very fine single grain, loose, very friable and non plastic. Concretions many.
13-39 cm B_1tc	2.5 YR 3/6 red brown sandy clay loam, with orange mottles (7.5 YR 6/6) and abundant gravels. Moderately strong, fine and medium sub-angular blocky, hard, firm and plastic. Concretions abundant
31-51 cm B_2x	Massive. Concretions dominant.

LTF1- D4

0-7 cm Ah	10 YR 2/2 brown black sandy loam, no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Many concretions.
7-17 cm ABt	10 YR 4/4 brown sandy clay loam few gravels. Weak to moderately strong, fine and medium sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant.
17-36 cm B_1t	2.5 YR 4/3 red brown sandy clay, abundant gravels. Moderately strong, fine medium and coarse sub-angular blocky, hard, firm and plastic. Concretions abundant.
36-58 cm B_2x	Massive. Dominanatly concretions

LTF1- D5

0-6 cm Ah	10 YR 2/2 brown black fine sandy loam, no gravel. Weak, very fine and fine granular, loose, friable and non plastic. Many concretions.
3-13 cm ABtc	10 YR 3/3 dark brown sandy loam many gravels. Weak to moderately strong, fine and medium sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant..
13-38 cm B_1tc	7.5 YR 4/4 brown sandy clay loam, abundant gravels. Moderately strong, fine medium angular blocky, hard, firm and plastic . Concretions abundant.
38-65 cm B_2x	Massive. Concretions dominant.

ABF1: Active bush farm #1

This land was broken about 4 years ago, and has since been in cultivation. Crops being produced are millet and cowpea. There are few shear nut trees on the farm. It is on the upper slope in relation to the uncultivated field. Generally, it is very gravelly and concretions are abundant. Planting is done on ridges. Land preparation by bullock ploughs and weeding done by hoe. Harvesting done manually. No fertilizer is applied.

ABF #1 B2

0-7 cm Apc	7.5 YR 2/2 brown black fine sandy loam with gravel. Weak, fine and very fine granular, soft, friable , non plastic and non sticky. Concretions abundant.
7-15 cm ABc	7.5YR 2/2 brown black sandy loam with gravel. Weak, moderately fine granular, soft, very friable , non plastic and non-sticky . Concretions abundant.
15-34 cm B_1tc	7.5YR4/4 sandy clay loam with orange mottles (7.5YR6/8) with abundant gravel. Moderately strong medium coarse single grain with very fine and fine roots, pores and channels. Fe and Mn concretions abundant.
34-44 cm B_2x	Massive. Concretion dominant.

ABF#1 B3

0-7 cm Apc	10YR2/2 brown black sandy loam with gravel. Weak, fine and very fine granular, soft, very friable , non plastic and non-sticky . Concretions abundant.
7-15cm ABc	10YR3/3 dark brown sandy clay loam with gravel. Weak to moderately strong, coarse single grain. Loose, friable, non plastic and non sticky. Concretions abundant.
15-28 cm B_1tc	10YR4/4 brown sandy clay loam with orange mottles (7.5YR7/6) and abundant gravel. Weak to moderately strong fine to medium sub-angular blocky, hard, firm, slightly plastic and slightly sticky. Fe and Mn concretions abundant.
28-45 cm B_2ct	10YR5/3 sandy clay no gravel. Moderately strong medium and coarse single grain. Hard, very firm, plastic and sticky . Concretions abundant.
45-71 cm B_3x	Massive. Concretions dominant.

ABF#1 B4 (same as main pit)

0-7 cm Apc	10YR2/1 black fine sandy loam with gravel. Weak, fine and very fine granular. Soft, friable, non plastic and non sticky. Fe and Mn concretions abundant.
7-19 cm	10YR2/2 brown black sandy clay loam with gravel. Weak to moderately strong, fine and

ABtc	medium single grain. Soft slightly hard to firm, lightly plastic and slightly sticky. Concretions abundant.
19-38 cm B_1tc	10YR3/4 bark brown sandy clay with gravel. Moderately strong, fine and medium single grain, slightly hard, firm, plastic and sticky. Concretions abundant.
38-56 cm B_2tc	10YR5/4 dull yellow brown sandy clay with yellowish orange mottles and gravel. Moderately strong, fine and medium single grain, hard, very firm, plastic and sticky. Concretions dominant
56-78 cm B_3x	Massive. Concretions dominant.

ABF#1 C2

0-5 Apc	10YR3/2 brown black fine sandy loam with gravel. Weak, fine and medium granular. Soft, very friable, non-plastic and non sticky. Concretions abundant.
5-14 cm ABc	10YR4/2 gray yellow brown fine sandy clay loam with abundant gravel. Weak to moderately strong, fine and medium sub-angular blocky. Slightly hard, friable to firm , slightly plastic and slightly sticky. Concretion abundant.
14-28 cm B_1tc	5YR3/3 dark red brown sandy clay with gravel. Moderately strong, very fine and fine single grain. Hard, firm, plastic and sticky. Concretions abundant.
28-50 cm B_2x	Massive. Concretions dominant.

ABF#1C3

0-6 cm Apc	10YR2/2 brown black sandy loam with gravel. Weak, fine to very fine granular. Soft , friable and non plastic. Concretions abundant.
6-16 cm ABtc	10YR3/3 dark brown sandy clay loam with gravel. Weak to moderately strong, fine and medium granular. Slightly hard, firm and slightly plastic. Concretions. abundant.
16-41 cm B_1tc	2.5YR3/4 dark red brown sandy clay with gravel. Moderately strong, fine and medium single grain, hard, very firm, plastic and sticky. Concretions dominant.
41-64 cm B_2x	Massive. Concretions dominant

ABF#1 C4

0-5 cm Apc	10YR3/1 brown black sandy loam no gravel. Weak, fine to very fine granular. Soft, friable, non plastic . Fe and Mn Concretions common.
5-11 cm ABc	10YR3/3 dull brown sandy clay loam with some gravel. Weak to moderately strong, fine and medium single grain. Soft to slightly hard, friable to firm , slightly plastic, slightly sticky. Concretions many.
11-24 cm B_1tc	2.5YR dull red brown clay loam with gravel. Moderately strong, fine and medium single grain, hard, firm and plastic . Concretions are abundant.
24-70 cm B_2x	Massive. Concretions dominant.

ABF#1 D2 (close to ant hills)

0-6 cm Apc	10YR sandy loam with gravel. Very weak, fine to medium granular. Soft , friable and, non plastic . Concretions common.
6-13 cm ABc	11 YR fine sandy loam with gravel. Moderately strong, fine and medium granular. Slightly hard, slightly firm and non plastic. Concretions many.
13-44 cm Bc	11 YR fine sandy loam with gravel. Moderately strong, fine and medium granular. Slightly hard, slightly firm and non plastic. Concretions many.

ABF#1 D3 (like a valley bottom soil))

0-5 cm Apc	10YR fine sandy loam no gravel. Strong, fine granular. Soft, friable and non-plastic. Concretions many.
5-13 cm AB	10YR sandy loam no gravel. Strong, fine and sub-angular blocky . Slightly hard , firm, slightly plastic. Concretions many.
13-40 cm B_1t	10YR sandy clay, no gravel. Strong, fine to very fine single grain.. Hard , firm to very firm and plastic and sticky. Concretions abundant..
40-65 cm B_2nt	10YR clay, no gravel. Strong, very fine single grain. Very hard, very firm, plastic and sticky. Concretions abundant.

ABF#1 D4 (close to threshing ground)

0-6 cm Ap	7.5YR2/2 brown black fine sandy loam, no gravel. Weak, fine and very fine granular. Soft , friable, non-plastic. Concretions common.
6-14 cm ABt	7.5YR3/2 dark brown fine sandy clay loam, no gravel. Weak, fine and medium granular. Slightly hard, firm , slightly plastic and slightly sticky. Concretions common.
14-29 cm B_1tc	10YR4/3 dull yellow brown fine sandy clay, no gravel. Moderately strong, fine and medium single grain. Dry, firm and plastic. Concretions many.
29-41 cm	10YR1/1 brown gray, no gravel. Moderately strong, fine and medium single grain. Hard, firm,

B_2tc	plastic and sticky. Concretions abundant.
41-70 cm B_{3tc}	10YR1/1 brown gray, no gravel. Moderately strong, fine and medium single grain. Hard, firm, plastic and sticky. Concretions abundant.

ABF2: Active bush farm #2

This site has been in cultivation for the last 7 years but has not been cultivated this year, probably due to the unreliable rainfall pattern this year. Hence could be taken as an active bush farm. Crops cultivated normally are, millet, and cowpea. Current vegetation is grasses and few shrubs. It is located in a lower slope position, and shows evidence of water-logging. The soil is generally sandy clay and imperfectly drained.

ABF#2 B2

0-5 cm Ap	5YR2/2 brown black fine sandy loam, no gravel. Weak, fine and medium granular. Soft, friable, non plastic and non sticky. Very few concretions.
5-11 cm ABc	5YR2/3 very dark red brown sandy loam with few gravel. Weak, fine and medium coarse granular. Slightly hard, friable, non plastic and non sticky. Very Few concretions.
11-24 cm B_1tc	5YR3/3 dark red brown fine sandy loam with some gravel. Moderately strong, fine and medium single grain. Slightly hard, friable, slightly plastic and slightly sticky. Concretions common.
24-64 cm B_2tc	5YR4/2 gray brown sandy clay. Weak, fine and medium coarse granular. Hard, friable, plastic and sticky. Mottles. Concretions common.

ABF#2 B3

0-8 cm Ap	5YR2/2 brown black fine sandy loam, no gravel. Weak, fine and medium granular. Soft, friable, non plastic and non sticky. Very few concretions.
8-17 cm ABt	5YR2/3 very dark red brown fine sandy loam with no gravel. Weak, fine and medium single grain. Loose, friable, non plastic and non sticky. Very few concretions.
17-37 cm B_1tc	5YR3/3 dark red brown sandy clay loam with orange mottles (7.5 YR6/8) no gravel. Weak, fine and medium sub-angular blocky. Slightly hard, firm, slightly plastic and slightly sticky. Very Few concretions.
37-67 cm B_2gtc	5YR 4/2 dark brown sandy clay. Moderately strong, fine and medium angular blocky. Hard, very firm, plastic and sticky. Very few concretions

ABF#2 B4

0-8 cm Ap	5YR2/2 brown black fine sandy loam no gravel. Weak, fine and medium granular. Soft, friable, non plastic and non sticky. Very few concretions.
8-12 cm ABt	5YR2/3 very dark red brown, sandy loam with few gravel. Weak, fine and medium granular. Slightly hard, friable, non plastic and non sticky. Mottles Very few concretions present.
12-27 cm B_1tc	5YR3/3 dark red brown fine sand loam with some gravel. Moderately strong, fine and medium single grain. Hard, very firm , plastic and sticky. Mottles Very few concretions.
27-72 cm B_2tc	5YR4/2 gray brown sandy clay with gravel. Moderately strong, fine and medium single grain. Hard, very firm, plastic and sticky. Mottles. Few Concretions

ABF#2 C2

0-7 cm Ap	7.5 YR2/1 brown black fine sandy loam, no gravel. Weak, fine and very fine granular. Soft , friable , non plastic and non sticky. Few concretions.
7-19 cm ABt	7.5YR3/4 dark brown fine sandy clay loam, no gravel. Weak, fine and medium granular. Soft to slightly hard, friable to firm, slightly plastic and non sticky. Mottles. Few concretions.
19-36 cm B_1t	7.5YR4/3 brown sandy clay loam, no gravel. Moderately strong fine and medium sub-angular blocky. Hard, firm, slightly plastic and slightly plastic Few concretions. Mottles.
36-66 cm B_2gtc	7.5YR 5/3 dull drown sandy clay, no gravel. Moderately strong fine, medium to coarse angular blocky. Hard, very firm, plastic and plastic. Concretions common.

ABF#2 C3

0-7 cm Ap	5YR2/2 brown black sandy loam no gravel. Weak, fine and very fine granular. Soft, friable, non plastic and non sticky. Very few concretions.
7-17 cm ABt	5YR2/2 drown black sandy clay loam no gravel. Weak, fine and medium granular Slightly hard, friable, slightly plastic and slightly sticky. Very few concretions.
17-36 cm B_1t	7.5 YR4/3 brown sandy clay with orange mottles (7.5YR6/8) no gravel. Weak to moderately strong, fine and medium sub-angular blocky. Hard , friable , plastic and sticky. Few Concretions.
36-56 cm B_2t	7.5YR5/4 dull brown clay. Moderately strong fine and medium angular blocky. Very hard, very firm,and plastic. Concretions common.

ABF#2 C4

0-6 cm Ap	5YR2/2 brown black fine sandy loam no gravel. Weak, fine and very fine granular. Soft, friable, non plastic and non sticky. No concretions.
6-17 cm ABt	5YR2/2 drown black sandy clay loam no gravel. Weak, fine sub-angular slightly hard, friable, slightly plastic and slightly sticky. No concretions
17-34 cm B_1t	7.5 YR4/3 brown sandy clay with orange mottles (7.5YR6/8) no gravels. Weak to moderately strong, fine and medium sub-angular blocky. Hard, friable, plastic and sticky. Very few Concretions .
34-72 cm B_2gt	7.5YR5/4 dull brown clay. Moderately strong fine and medium angular blocky. Very hard, very firm, plastic and plastic. Concretions very few.

ABF#2 D2

0-5 cm Ap	10YR fine sandy loam no gravel. Weak, fine to very fine granular. Soft, friable, non plastic and non sticky. Few concretions
5-16 cm AB	10YR fine sandy loam no gravel. Weak, fine to very fine granular. Soft, friable, non plastic and non sticky. Few concretions.
16-38 cm B_1t	10YR sandy clay loam, no gravel. Weak, fine sub-angular slightly hard, friable, slightly plastic and slightly sticky. No concretions.
38-64 cm B_2t	7.5YR sandy clay with orange mottles (7.8YR6/8). Weak, fine sub-angular. Hard, firm, plastic and sticky. Few concretions
64-84 cm B_3gt	5YR4/2gray brown clay with orange mottles (7.8YR6/8). Weak, fine sub-angular. Hard, firm, plastic and sticky. Few concretions

ABF#2 D3

0-6 cm Ap	10YR very fine sandy loam, no gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Few concretions
6-19 cm ABt	10YR sandy clay loam. Weak to moderately strong, fine sub-angular, slightly hard, firm and plastic. Few concretions
19-34 cm B_1t	10YR sandy clay loam with some gravel. Moderately strong and medium angular, slightly hard, firm , plastic and sticky. Few concretions.
34-58 cm B_2tc	5YR4/2 gray brown sandy clay, some gravel. Strong, medium and coarse angular blocky, hard, firm, plastic and sticky. Few concretions.
58-73 cm B_3gtc	5YR4/2 gray brown clay. Strong, medium and coarse angular blocky structure, very hard, very firm, plastic and sticky. Concretions common.

ABF#2 D4

0-5 cm Ap	7.5 YR fine sandy loam, no gravel with weak, fine and very fine granular. Soft , friable, and non plastic. Very few concretions.
5-15 cm AB	7.5 YR sandy clay loam, no gravel. Weak, fine and very fine single grain. Soft, friable and non plastic. Very few concretions
15-39 cm B_1	7.5YR sandy clay loam no gravel. Weak, fine and very fine single grain, soft, friable and non plastic. Very few concretions.
39-63 cm B_2tc	5YR sandy clay with orange mottles (7.5YR7/8). Moderately strong, fine and medium sub-angular, hard , firm, plastic. Very Few concretions.
63-75 cm B_3gtc	5YR clay Strong, medium and coarse angular blocky, very hard, very firm, plastic and sticky when wet. Very Few concretions.

Active bush farm # 3

Millet intercropped with cowpea, near the 50 year fallow. In relation to the 50 year fallow, it is in a lower slope position.The soil is very sandy and deep especially lower down the slope towards the north. Cultivation is by bullock plough, with no fertilizer or agrochemicals. Weeding is done manually. It has been in cultivation for the past 4 years.

ABF #3 B2

0-6 cm Apc	7.5 2/2 brown black fine sandy loam with gravel. Weak, fine and very fine granular, soft, friable , non plastic. Concretions common.
6-13 cm ABtc	10 YR 2/3 brown black fine sandy clay loam with abundant gravel. Weak to moderately strong, fine and medium sub-angular blocky. Slightly hard, firm, slightly plastic and sticky. Concretions common.
13-38 cm	10 YR4/2 gray yellow brown sandy clay with orange mottles, 7.5 YR 6/8 and abundant gravel.

B_1tc	Moderately strong, fine and medium angular. Hard, firm, plastic and sticky . Fe and Mn concretion many.
38-67 cm B_2tc	10 YR4/2 gray yellow brown sandy clay with orange mottles, 7.5 YR 6/8 and abundant gravel. Moderately strong, fine and medium angular. Hard, firm, plastic and sticky . Fe and Mn concretion abundant.

ABF#3 B3

0-5 Ap	5YR3/brown black Fine sandy loam no gravel with very weak, very fine granular. L oose, friable and non plastic and non sticky. Few concretions.
5-16 cm ABt	5YR3/3 dark gray brown fine sandy clay loam no gravel Weak to moderately strong, fine and medium granular. Soft, slightly firm and slightly plastic and sticky. Few concretions.
16-32 cm B_1tc	5YR 4/2 gray brown sandy clay with gravel. Moderately strong, fine and medium sub-angular blocky. Slightly hard to hard, firm, plastic and sticky Many concretions.
32-65 cm B_2gtc	5YR5/2 gray brown clay with dark red brown mottled 2.5 YR3/6. Strong to medium angular. Hard, very firm, plastic and sticky. Concretions many

ABF#3 B4

0-6 cm Ap	7.5 YR Sandy clay loam, no gravel. Weak, fine to medium granular, soft, friable and non plastic. Few concretions
6-17 cm ABt	7.5 YR sandy clay loam, no gravel. Weak to moderately strong, fine and medium granular. Slightly hard, firm, and plastic. Few concretions.
17-38 cm B_1tc	7.5 YR clay loam no gravel. Moderately strong, coarse and medium granular. Hard, firm and plastic. Concretions many.
38-66 cm B_2x	7.5 YR clay loam no gravel. Moderately strong, coarse and medium granular. Hard, firm and plastic. Concretions abundant.

ABF#3 C2

0-7 cm Ap	5 YR 2/2 fine sandy loam no gravel. Weak , fine , very fine granular. Soft, friable, non plastic and non sticky. Many concretions.
7-16 cm ABtc	5YR3/2 fine sandy clay with gravel. Weak, fine and medium granular. Soft to slightly hard, slightly plastic and slightly sticky. Concretions many.
16-28 cm B_1tc	5YR 4/2 sandy clay with abundant gravel. Moderately strong, medium to very fine sub-angular. Hard, firm, plastic and sticky. Concretions abundant.
28-60 cm B_2x	Massive. Concretions dominant.

ABF #3 C3

0-7 cm Ap	10YR2/2 brown black fine sandy loam no gravel. Weak, fine very fine granular. Loose, friable and non plastic and non sticky. Few concretions.
7-15 cm ABtc	10YR3/2 brown black sandy clay loam, gravel. Weak, fine and medium granular. Slightly hard, firm, slightly plastic and slightly sticky.Concretions many.
15-34 cm B_1tc	10YR3/4 dark brown sandy clay with orange mottles 7.5YR6/8, and gravel. Weak to moderately strong, fine and medium sub-angular blocky, hard, firm, plastic and sticky. Concretions many.
34-70 cm B_2tc	10YR5/3 dull red sandy clay with yellow orange mottles 7.5YR7/8 no gravel. Moderately strong fine and medium angular. Hard, very firm, plastic and sticky. Concretions many
70-85 cm B_3gtc	Clay with strong medium and coarse angular blocky, very hard, firm Plastic and sticky. Concretions abundant.

ABF#3 C4

0-6 cm Ap	5YR sandy loam no gravel. Weak, fine to very fine granular. When dry is soft, friable moist and slightly plastic when wet. Very few concretions.
6-13 cm ABtc	5YR sandy clay loam with gravel. Weak to moderately strong fine sub-angular. Slightly hard, friable to firm, slightly plastic and slightly sticky. Very few concretions.
13-65cm B_1tc	5YR clay loam with gravel. Moderately strong fine angular. Hard, very firm, plastic and sticky. Few concretions..

ABF#3 D2

0-6 cm Ap	7.5YR2/2 brown black fine sandy loam no gravel. Weak, fine and medium granular. Soft, friable , non plastic and non sticky. Concretions common.
6-13 cm ABt	7.5YR2/3 very dark brown sandy clay loam no gravel. Weak, fine and medium granular. Soft to slightly hard, firm, slightly plastic and slightly sticky. Concretions common.
13-22 cm B_1tc	7.5YR 4/4 brown sandy clay loam with orange mottles (7.5YR6/8) gravel. Weak to moderately strong fine sub-angular. Hard, firm, plastic and sticky. Concretions common.
22-66 cm B_2	7.5YR 4/4 brown sandy clay loam with orange mottles (7.5YR6/8) gravel. Weak to moderately

	strong fine sub-angular. Hard, firm, plastic and sticky. Concretions many.

ABF#3 D3

0-6 cm Apc	10YR2/1 black fine sandy loam, no gravel. Very weak, very fine granular. Soft, friable, non plastic and non sticky. Few concretions
6-18 cm ABtc	10YR2/3 brown black sandy clay loam, no gravel. Weak, fine granular. Slightly hard, firm, slightly plastic and slightly sticky. Few concretions
18-45 cm B_1tc	10YR4/2 gray yellow sandy clay with orange mottles (7.5YR6/8), gravel. Weak to moderately strong, fine and medium sub angular blocky. Hard, firm, plastic and sticky. Concretion common.

ABF#3 D4

0-6 cm Ap	7.5YR2/2 brown black fine sand clay no gravel. Weak , fine and medium granular. Soft, friable, non plastic and non sticky. Very few concretions
6-13 cm ABtc	7.5 YR3/4 dark brown sandy clay loam, no gravel. Weak to moderately strong, fine and medium granular blocky. Slightly hard, firm, slightly plastic and slightly sticky. Very few oncretions.
13-64 cm B_1tc	7.5 YR 4/3 brown sandy clay with gravel. Weak to moderately strong, fine and medium sub angular blocky. Hard, firm, plastic and sticky. Few concretions..

STF1: Fallowed bush farm Fallowed for 4 years. Cultivated with bullock and crops include millet, cowpea and sorghum. No fertilizer was used. It is on a slightly high ground. Very gravelly and concretionary. Current vegetation is grass.

STF#1 B2

0-7 cm Apc	10YR3/2 brown black fine sandy loam with gravel. Weak, fine and medium granular, soft, friable and non plastic. Concretions common.
7-19 cm ABtc	10YR dull yellow brown fine sandy loam with gravel. Moderately strong, medium and coarse sub-angular. Slightly hard, firm, slightly plastic and slightly sticky. Concretions many
19-31 cm B_1tc	10YR5/2 gray yellow brown sandy clay loam with orange mottles (7.5 YR7/6) and gravel. Moderately strong, medium and coarse sub-angular Slightly hard, firm, slightly plastic and slightly sticky. Concretions abundant.
31-45 cm B_2x	Massive. Concretion dominant.

STF#1 B3

0-11 Apc	5YR 2/1 brown black fine sandy loam with gravel. Weak, fine and medium granular. Loose, friable and non plastic. Concretions common.
11-21 cm ABtc	5YR 2/1 brown black fine sandy clay loam with gravel. Moderately strong, medium and coarse granular, soft and very friable and non plastic. Concretions common.
21-40 cm B_1tc	5YR5/1 Gray brown fine sandy clay loam. Moderately strong, medium sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant.
40-58 cm B_2tc	5YR6/2 gray brown fine sandy clay. Moderately strong coarse sub-angular blocky, very hard, very firm and plastic. Concretions abundant
58-78 cm B_3x	Massive. Concretion dominant.

STF#1 B4

0-7 cm Apc	10YR 3/2 brown black fine sandy clay with gravel. Weak, fine and medium granular, loose, friable, non plastic and non sticky . Concretions common.
7-19 cm ABtc	10YR 3/3 dark brown sandy clay loam with gravel. Moderately strong medium sub-angular blocky, slightly hard, firm to very firm, slightly plastic. Concretions abundant.
19-45 cm B_1x	10 YR5/2 gray yellow massive dominantly concretion..

STF#1 C2

0-6 cm Apc	10YR 3/4 dark red brown, fine sandy loam. Weak, fine and very fine granular, loose, very friable and non-plastic. Concretions many
6- 16 cm ABc	10YR5/4 dark red brown, fine sandy loam with gravel. Weak to moderately strong fine and medium granular. Soft to slightly hard, firm, slightly plastic and slightly sticky. Concretions abundant.
16-32 cm B_1tc	10YR 5/6 sandy clay loam with gravel. Moderately strong fine and medium sub-angular blocky. Hard, firm, and plastic . Concretions dominant
32-52 cm B_2x	Massive. Concretion dominant.

STF#1 C3

0-7 cm Apc	10YR3/4 dark brown fine sandy loam with gravel. Weak, fine and very fine granular, loose, friable, non plastic and non sticky. Concretions many.

7-16 cm ABc	10 YR 4/4 brown fine sandy loam with gravel. Moderate to strong medium and coarse sub-angular blocky. Slightly hard to hard, firm slightly plastic and slightly sticky. Concretions abundant.
16-23 cm B_1tc	10YR5/6 yellow brown fine sandy clay loam with gravel . Moderate to strong medium coarse sub-angular blocky. Slightly hard to hard, firm, and slightly plastic Concretions abundant.
23-50 cm B_2x	Massive. Concretion dominant.

STF#1 C4

0-7 cm ABpc	10YR3/3 dark brown fine sandy loam with gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions many.
7-22 cm B_1c	10 YR 5/3 brown fine sandy loam with orange mottles and gravel. Weak, fine and very fine granular, slightly hard, firm, slightly plastic and slightly sticky. Concretions abundant.
22-36 cm B_2x	Massive and dominantly concretion.

STF#1 D2 (Same as pit)

0-7 cm ABpc	10YR 2/3 brown black fine sandy loam with gravel. Weak, very fine and fine granular, soft, friable and non plastic. Concretions common.
7-17 cm B_1c	10YR 4/4 brown fine sandy clay loam with faint mottles bright brown (7.5 YR6/6) and gravel. Weak, fine and coarse sub-angular blocky, slightly hard, firm and plastic. Concretions common.
17-45 cm B_2x	10 YR 5/2 gray yellow brown sandy clay with abundant concretion

STF#1 D3

0-9 cm Apc	10YR 2/3 brown black fine sandy loam with gravel. Weak, very fine and fine granular. Loose friable and non plastic. Concretions abundant.
9-21 cm ABc	10YR 4/6 brown fine sandy clay loam with faint mottles orange (7.5 YR6/8) and gravel. Weak, fine and coarse sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant.
21-37 cm B_1tc	10 YR 5/6 yellow brown, sandy clay. Concretions dominant.
37-62 cm B_2x	Massive. Concretions dominant.

STF#1 D4

0-7 cm Apc	10YR 3/4 dark brown fine sandy loam. Weak, fine and medium granular, soft, friable and non plastic. Concretions common.
7-13 cm ABtc	10YR 5/4 dull yellow brown fine sandy clay loam with distinct dull red brown mottles (2.5 YR5/3) and gravel. Weak, fine and coarse sub-angular blocky, slightly hard, firm and slightly plastic. Concretions abundant.
13-38 cm B_1tc	10 YR 5/2 gray yellow brown, sandy clay. Concretions dominant
38-48 cm B_2x	Massive. Concretions dominant.

CF1: Compound farm #1

Farm belonging to the chief's household. It is on an upper slope. Crops grown include, early millet, cowpea ans late millet and vegetables. The farm is fertilized with household refuse and animal dropping. The amount of animal manure applied depends on the number of animals the household possess. Generally the soil is very gravelly.

CF#1 B2

0-5 cm Apc	5YR2/2 brown black fine sandy loam with few gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions abundant.
5-11 cm ABc	5YR 2/3 very dark red brown sandy loam with gravel. Weak, fine and medium granular. Slightly hard, friable to firm, slightly plastic. Concretions abundant.
11-28 cm B_1tc 28-55 cm B_2x	5YR4/6 red brown sandy clay loam with bright reddish brown mottle (2.5YR 5/8) and abundant gravel. Moderately strong, fine and medium single grain. Slightly hard to hard, firm and slightly plastic. Concretions abundant. Bx horizon is massive and dominantly concretions.

CF#1 B3

0-5 cm Apc	7.5YR2/2 brown black fine sandy loam with few gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions abundant.
5-12 cm ABtc	7.5YR 3/4 very dark red brown fine sandy loam with gravel. Weak, fine and medium granular, slightly hard, friable to firm, slightly plastic. Concretions abundant.
12-25 cm B_1tc	2.5YR3/6 dark red brown fine sandy clay loam with abundant gravel. Moderately strong, fine and medium single grain, slightly hard to hard, firm and slightly plastic. Concretion abundant.
25-41 cm B_2x	Massive. Concretion dominant.

CF#1 B4

0-6 cm Apc	2.5YR2/2 very dark red brown fine sandy loam with few gravel. Weak, fine and very fine granular, soft when dry, friable, non plastic and non sticky. Concretions many.
6-14 cm ABtc	2.5YR 2/3 very dark red brown fine sandy loam with gravel. Weak, fine and medium granular. Slightly hard, friable to firm, slightly plastic. Concretions abundant.
14-34 cm B_1tc	2.5YR3/2 dark red brown fine sandy clay loam with abundant gravel. Moderately strong, fine and medium single grain. Slightly hard to hard, firm and slightly plastic. Concretions abundant.
34-51 cm B_2x	Massive. Concretions dominant.

CF#1 C2 (Up land)

0-7 cm Apc	5YR2/2 brown black fine sandy loam with few gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions abundant.
7-16 cm ABc	5YR 2/3 very dark red brown sandy loam with gravel. Very weak, fine and medium single grain, slightly hard, friable to firm, slightly plastic. Concretions abundant.
16-37 cm B_1tc	5YR3/2 dark red brown fine sandy clay with abundant gravel. Moderately strong, medium and coarse sub-angular blocky. Slightly hard to hard, firm and slightly plastic. Concretions abundant.
37-65 cm B_2x	Massive. Concretions dominant.

CF#1 C3(Upland, very shallow, hard pan close to surface)

0-5 cm Apc	7.5YR3/2 brown black fine sandy loam with few gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions abundant.
5-11 cm Abc 11-25 cm B_1x	2.5YR 3/2 dark red brown sandy loam with gravel. Weak, fine and medium granular, slightly hard, friable, slightly plastic. Concretions abundant. Bx is massive and dominantly concretions.

CF#1 C4

0-6 cm Apc	10YR2/1 fine sandy loam with few gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions many.
6-13 cm ABc	10YR2/2 loamy fine sand with gravel. Weak, fine and medium granular. Slightly hard, friable, slightly plasticand sticky. Concretions abundant.
13-27 cm B_1tc	7.5YR sandy clay loam with abundant gravel. Moderately strong, fine and medium single grain. Slightly hard, firm and slightly plastic. Concretions abundant.
27-35 cm B_2x	Massive

CF#1 D2

0-7 cm Apc	7.5 YR2/2 brown black sandy loam with few gravel. Weak, fine and medium granular, soft, very friable, non plastic and non sticky. Concretions many.
7-16 cm ABc	7.5 YR2/3 very dark brown sandy loam with gravel. Weak, fine and medium granular. Soft, friable, slightly plastic. Concretions abundant.
16-25 cm B_1tc 25-42 cm B_2x	5YR3/4 sandy clay loam (2.5 YR 5/6) and abundant gravel. Moderately strong, medium and coarse angular blocky. Slightly hard, firm and slightly plastic. Concretions abundant. Bx is massive

CF#1 D3

0-7 cm Apc	2.5YR2/1 very fine sandy loam with few gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions many.
7-15 cm B_1c	2.5YR 3/2 fine sandy loam with gravel. Weak, fine and medium granular. Slightly hard, friable to firm, slightly plastic. Concretions abundant.
15-29 cm ABtc	2.5YR3/4 medium sandy loam with abundant gravel. Moderately strong, fine and medium single grain. Slightly hard to hard, firm and slightly plastic. Concretions abundant.
29-53 cm B_1Ctc	2.5 YR4/4 medium sandy clay with abundant gravel. Moderately strong, fine and medium single grain, slightly hard to hard, firm and slightly plastic. Concretions abundant.
53-96 cm B_2x	2.5 YR 4/6 Massive.

Compound farm #2

It is located in a lower slope position. The soil is very sandy. Crops cultivated include, early millet, late millet, cowpeas and vegetables. Fertility is maintained with house hold refuse and animal manure. Cultivation ia done with bullock pough, while weeding is done manually. No fertilizer and agrochemicals are applied.

CF#2 B2

0-5 cm Ap	5YR2/2 brown loamy sand with no gravel. Weak, fine and medium granular, soft, friable, non plastic and non sticky. Concretions common.
5-11 cm A_2c	5YR 2/3 very dark red loamy sand with gravel. Structure is weak, fine and medium granular. Slightly hard, friable to firm, slightly plastic. Concretions common
11-24 cm	5YR3/3 dark red brown loamy fine sand with abundant gravel. Moderately strong, medium single

B_1tc	grain. Slightly hard to hard, firm and slightly plastic. Concretions many
24-61 cm B_2tc	5YR4/2 gray brown sandy loam with abundant gravel. Moderately strong, medium single grain. Consistence is slightly hard to hard, firm and slightly plastic. Concretions abundant.

CF#2 B3

0-7 cm Apc	5YR2/2 brown black fine loamy sand with gravel. Very weak, fine and medium granular, soft, friable, non plastic and non sticky. Concretions common.
7-16 cm A_2c	5YR 3/1 brown black fine loamy sand with gravel. Weak, coarse granular. Consistence is slightly hard, friable to firm, slightly plastic. Concretions common.
16-37 cm B_1tc	7.5YR5/4 dull brown fine sandy loam with abundant gravel. Moderately strong, medium single grain. Slightly hard to hard, firm and slightly plastic. Concretions many.
37-65 cm B_2gtc	5YR4/2 gray brown sandy loam with abundant gravel. Moderately strong, medium single grain. Slightly hard to hard, firm and slightly plastic. Concretions many.

CF#2 B4

0-19 cm Ap	7.5 YR 3/3 brown black loamy very fine sand with no gravel. Very weak, fine and medium granular. Soft, friable non plastic and non sticky. Concretions common.
19-43 cm B_1c	7.5YR 4/3 brown black loamy fine sand with no gravel. Structure is moderately strong medium sub-angular. Slightly hard, friable to firm, slightly plastic. Concretions many
43-55cm B_2gtc	7.5YR 4/3 brown black loamy fine sand with no gravel. Structure is moderately strong medium sub-angular. Slightly hard, friable to firm, slightly plastic. Mottles and abundant concretions.

CF#2 C2 (same as main pit, chisel hole is 56 cm deep)

0-16cm Ap	5 YR 3/4 dark brown loamy sand with no gravel. Very weak, fine and granular. Soft, friable, non plastic and non sticky. Concretions common.
16-37 cm ABc	5YR 4/6 brown black loamy fine sand with no gravel. Weak, medium granular. Slightly hard, friable to firm, slightly plastic. Concretions many.
37-61 cm B_1tc	7.5YR 4/3 brown black loamy fine sand with yellowish orange mottles with and gravel. Moderately strong medium sub-angular. Slightly hard, friable to firm, slightly plastic. Concretions abundant.
61-104cm B_2x	Massive and dominantly concretions

CF#2 C3 (close to a grave)

0-11cm Ap	7.5 YR 3/4 dark brown loamy fine sand with few gravel. Very weak, fine and granular, soft, friable, non plastic and non sticky. Concretions common.
11-17 cm ABc	7.5YR 4/6 brown black loamy fine sand with few gravel. Weak, fine sub-angular. Slightly hard, friable to firm, slightly plastic. Concretions common.
17-34 cm B_1c	7.5YR 5/3 brown black loamy fine sand with dull orange mottles with and gravel. Moderately strong medium sub-angular. Slightly hard, friable to firm, slightly plastic. Concretions common.
34-56 cm B_2	7.5YR 5/3 brown black loamy fine sand with dull orange mottles with and gravel. Moderately strong medium sub-angular. Slightly hard, friable to firm, slightly plastic Concretions many.

CF#2 C4

0-7cm Ap	5 YR 2/2 brown loamy fine sand no gravel. Very weak, fine and very fine granular. Soft, friable, non plastic and non sticky. Concretions common.
7-17 cm ABc	5YR 3/3 brown black loamy sand no gravel. Weak, fine very fine single grain. Soft, very friable, non plastic. Concretions common.
17-36 cm B_1c	7.5YR 4/3 brown loamy sand no gravel. Weak, fine single grain, soft, very friable, and non plastic. Concretions common.
36-58 cm B_2gtc	7.5YR 5/4 dull brown sandy clay loam with bright red brown orange mottles (2.4YR5/8) with and gravel. Moderately strong medium sub-angular, hard, firm, plastic and sticky. Concretions many..

CF#2 D2

0-5cm Ap	7.5 YR loamy sand no gravel. Weak, fine and very fine granular with pores and roots. Consistence is soft, friable, non plastic and non sticky. Concretions common.
5-14 cm A_2	7.5YR loamy sand no gravel. Weak to moderatley strong, fine and medium sub-angular. Slightly hard, firm, slightly plastic. Concretions common.
14-22 cm ABtc	7.5YR loamy sand no gravel. Moderately strong, fine and medium angular blocky, hard, firm, plastic and sticky. Concretions common.
22-38 cm B_1tc	7.5YR 5/4 dull brown sandy clay with bright red brown orange mottles (2.4YR5/8) with and gravel. Moderately strong medium angular blocky. Very hard, very firm, and plastic.

	Concretions common
38-56 cm B_2c	7.5YR 5/4 dull brown sandy clay with bright red brown orange mottles (2.4YR5/8) with and gravel. Moderately strong medium angular blocky. Very hard, very firm, and plastic. Concretions many

CF#2 D3

0-7cm Ap	7.5 YR2/3 brown loamy fine sand no gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Concretions common.
7-17 cm A_2t	7.5YR 3/4 dark brown sandy clay loam no gravel. Weak to moderatley strong, fine and medium granular. Slightly hard, firm , slightly plastic. Concretions many
17-36 cm B_1tc	7.5YR 4/3 brown sandy clay with gravel. Moderately strong, fine and medium sub-angular blocky, hard, firm, plastic. Concretions abundant.
36-56 cm B_2gtc	7.5YR 5/3 dull brown sandy clay with bright red brown orange mottles (2.4YR5/8) with and gravel. Moderately strong medium angular blocky, very hard, very firm, and plastic. Concretions abundant.

CF#2 D4

0-11cm Apc	5 YR 2/2 very dark red brown loamy fine sand no gravel. Very weak, fine and granular, soft, friable, non plastic and non sticky. Concretions common.
11-22 cm AB	5YR 3/3 dark reddish brown loamy sand with few gravel. Structure is medium coarse single grain. Slightly hard, friable to firm, slightly plastic.Concretions common
22-58 cm B_1tc	5YR 5/3 brown black loamy sand with dull orange mottles with and gravel. Structure is moderately strong medium sub-angular. Slightly hard, friable to firm, slightly plastic. Concretions many.

SITE AND PROFILE DESCRIPTION (1997 sites)

Note: Due to a communications mix-up in the field, horizons at sites STF2, ABF4, ABF4, ABF5, ABF6, and ABF7 were described in 10 cm increments rather than by natural horizon boundaries.

STF2

In a flood plain with signs of seasonal water logging. Was cultivated to rice, abandoned for bird pests.

STF#2 1A

0-10 cm A_1	10YR6/1 Brown fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel. Very few concretions.
10-20 cm A_2	10YR5/1 Grey sandy clay loam. Weak fine granular , soft friable and slightly plastic. No gravel Very few concretion
20-30cm AB	10YR5/4 Light grey gritty clay loam, weak subangular, slightly firm and slightly plastic. Few concretions
30-40 cm Bt	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Concretions common.

STF#2 1B

0-10 cm A_1	10YR6/1 Brown fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel. Very few concretions.
10-20 cm A_2	10YR5/1 Grey silty fine clay,. Weak fine granular , soft friable and slightly plastic. No gravel Very few concretion
20-30cm AB	10YR5/4 Light grey gritty clay loam, weak subangular, slightly firm and slightly plastic. Very Few concretions
30-40 cm Bt	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Few concretions

FBF#2 1C

0-10 cm A_1	10YR6/1 Brown fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel no concretions.
10-20 cm A_2	10YR5/1 Grey silty fine clay loam. Weak fine granular , soft friable and slightly plastic. No gravel Few concretion
20-30cm AB	10YR5/4 Light grey gritty clay loam, weak subangular, slightly firm and slightly plastic. Few concretions
30-40 cm Bt	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Concretions common.

STF#2 2A

0-10 cm A_1	10YR6/1 Brown silty fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel Very few concretions.
10-20 cm A_2	10YR5/1 Grey silty clay loam with yellowish brown mottles. Weak fine granular , soft friable and slightly plastic. No gravel. Concretions few
20-30cm AB	10YR5/4 Light grey clay loam with brownish yellow mottles weak subangular, slightly firm and slightly plastic. Few concretions
30-40 cm Bt	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Concretions common.

STF#2 2B

0-10 cm A_1	10YR6/1 Brown silty fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel. Very few concretions.
10-20 cm A_2	10YR5/1 Grey silty clay loam with yellowish brown mottles. Weak fine granular , soft friable and slightly plastic. Few gravels. Concretions common.
20-30cm ABc	10YR5/4 Light grey fine sandy clay loam with brownish yellow mottles weak subangular, slightly firm and slightly plastic. Many concretions
30-40 cm Btc	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Many concretions

STF#2 2C

0-10 cm A_1	10YR6/1 Brown silty fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel. Few concretions.
10-20 cm A_2	10YR5/1 Grey sandy clay with yellowish brown mottles. Weak fine granular , soft friable and slightly plastic. Gravels and concretion common.
20-30cm ABc	10YR5/4 Light grey sandy clay loam with brownish yellow mottles weak subangular, slightly firm and slightly plastic. Concretions and gravels many.
30-40 cm Btc	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Concretions many

STF#2 3A

0-10 cm A_1	10YR6/1 Brown sandy loam. Weak, fine granular, soft friable and non plastic. No gravel Few concretions.
10-20 cm A_2	10YR5/1 Grey sandy clay with yellowish brown mottles. Weak fine granular , soft friable and slightly plastic. No gravel Few concretion
20-30cm AB	10YR5/4 Light grey sandy clay loam with brownish yellow mottles weak subangular, slightly firm and slightly plastic. Concretions common.
30-40 cm Bt	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Concretions common.

STF#2 3B

0-10 cm A_1	10YR6/1 Brown Sandy loam. Weak, fine granular, soft friable and non plastic. No gravel Few concretions.
10-20 cm A_2	10YR5/1 Grey sandy clay with yellowish brown mottles. Weak fine granular , soft friable and slightly plastic. No gravel. Concretion common.
20-30cm ABc	10YR5/4 Light grey gritty clay loam with brownish yellow mottles weak subangular, slightly firm and slightly plastic. Many concretions
30-40 cm Btc	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Many concretions

STF#2 3C

0-10 cm A_1	10YR6/1 Brown fine sandy loam. Weak, fine granular, soft friable and non plastic. No gravel. Concretions common.
10-20 cm A_2	10YR5/1 Grey fine sandy clay loam with yellowish brown mottles. Weak fine granular , soft friable and slightly plastic. Gravels and concretion common.
20-30cm ABc	10YR5/4 Light grey sandy clay loam with brownish yellow mottles weak subangular, slightly firm and slightly plastic. Concretions and gravels many
30-40 cm Btc	10YR5/4 Light grey clay loam with brownish yellow mottles and occasional manganese stains. Hard, subangular, plastic. Abundant concretions

LTF2

Long-term fallow of about 20-30 years. Very concretionary with hard pans exposed

LTF2- 1A

0-7 cm A1	7.5 YR 2/2 brown black fine sandy loam with gravel. Weak, fine and very fine granular, soft, friable, non plastic and non sticky. Few concretions.
7-15 cm ABc	7.5YR 2/2 brown black loamy fine sand with gravel. Weak, moderately fine granular, soft, very friable, non plastic and non-sticky. Concretions common.
15-34 cm B_1tc	7.5YR4/4 sandy clay loam with orange mottles (7.5YR6/8) with abundant gravel. Moderately strong medium coarse blocky with very fine and fine roots, pores and channels. Fe and Mn concretions abundant.
34-44 cm B_2x	Massive. Concretion dominant.

LTF2- 1B

0-7 cm A1	10YR2/2 brown black sandy clay loam with gravel. Weak, fine and very fine granular, soft, very friable, non plastic and non-sticky. Concretions common.
7-15cm ABc	10YR3/3 dark brown loamy fine sand with gravel. Weak to moderately strong, coarse single grain. Loose, friable, non plastic and non sticky. Concretions abundant.
15-28 cm B_1tc	10YR4/4 brown sandy clay loam with orange mottles (7.5YR7/6) and abundant gravel. Weak to moderately strong fine to medium sub-angular blocky, hard, firm, slightly plastic and slightly sticky. Concretions abundant.
28-45 cm B_2ct	10YR5/3 sandy clay no gravel. Moderately strong medium and coarse blocky. Hard, very firm, plastic and sticky. Concretions dominant.
45-71 cm B_3x	Massive. Concretions dominant.

LTF2- 1C

0-7 cm A1	10YR2/1 black fine sandy loam with gravel. Weak, fine and very fine granular. Soft, friable, non plastic and non sticky. Few concretions.
7-19 cm ABt	10YR2/2 brown black sandy clay loam with gravel. Weak to moderately strong, fine and medium blocky. Soft slightly hard to firm, lightly plastic and slightly sticky. Concretions common.
19-38 cm B_1tc	10YR3/4 bark brown sandy clay with gravel. Moderately strong, fine and medium blocky, slightly hard, firm, plastic and sticky. Concretions abundant.
38-56 cm B_2tc	10YR5/4 dull yellow brown sandy clay with yellowish orange mottles and gravel. Moderately strong, fine and medium blocky, hard, very firm, plastic and sticky. Concretions abundant
56-78 cm B_3x	Massive. Concretions dominant.

LTF2- 2A

0-5 A1	10YR3/2 brown black fine sandy loam with gravel. Weak, fine and medium granular. Soft, very friable, non-plastic and non sticky. Few concretions.
5-14 cm AB	10YR4/2 gray yellow brown fine sandy clay loam with abundant gravel. Weak to moderately strong, fine and medium sub-angular blocky. Slightly hard, friable to firm, slightly plastic and slightly sticky. Concretion common.
14-28 cm B_1tc	5YR3/3 dark red brown sandy clay with gravel. Moderately strong, very fine and fine blocky. Hard, firm, plastic and sticky. Concretions abundant
28-50 cm B_2x	Massive. Concretions dominant.

LTF2- 2B

0-6 cm Apc	10YR2/2 brown black sandy loam with gravel. Weak, fine to very fine granular. Soft, friable and non plastic. Concretions abundant.
6-16 cm ABtc	10YR3/3 dark brown sandy clay loam with gravel. Weak to moderately strong, fine and medium granular. Slightly hard, firm and slightly plastic. Concretions abundant.
16-41 cm B_1tc	2.5YR3/4 dark red brown sandy clay with gravel. Moderately strong, fine and medium blocky, hard, very firm, plastic and sticky. Concretions dominant
41-64 cm B_2x	Massive Concretions dominant.

LTF2- 2C

0-5 cm Apc	10YR3/1 brown black sandy loam no gravel. Weak, fine to very fine granular. Soft, friable, non plastic. Abundant Concretions.
5-11 cm ABc	10YR3/3 dull brown sandy clay loam with some gravel. Weak to moderately strong, fine and medium blocky. Soft to slightly hard, friable to firm, slightly plastic, slightly sticky. Concretions abundant.
11-24 cm	2.5YR dull red brown clay loam with gravel. Moderately strong, fine and medium blocky, hard,

B_1tc	firm and plastic. Concretions dominant.
24-70 cm B_2x	Massive. Concretions dominant

LTF2- 3A

0-6 cm Ap	10YR sandy loam with gravel. Very weak, fine to medium granular. Soft, friable and, non plastic . Concretions few.
6-13 cm AB	11 YR fine sandy loam with gravel. Moderately strong, fine and medium granular. Slightly hard, slightly firm and non plastic. Concretions common.
13-44 cm B_2xc	11 YR fine sandy loam with gravel. Moderately strong, fine and medium granular. Slightly hard, slightly firm and non plastic. Massive and abundant concretions

LTF2- 3B

0-5 cm Apc	10YR fine sandy loam no gravel. Strong, fine granular. Soft, friable and non-plastic. Abundant concretions.
5-13 cm ABc	10YR sandy loam, gravel. Strong, fine and sub-angular blocky . Slightly hard , firm, slightly plastic. Abundant concretions.
13-40 cm B_1tc	10YR sandy clay, gravel. Strong, fine to very fine blocky.. Hard , firm to very firm and plastic and sticky. Concretions dominant.
40-65 cm B_2tc	10YR clay, no gravel. Strong, very fine blocky. Very hard, very firm, plastic and sticky. Concretions dominant.

LTF2 3C

0-6 cm Ap	7.5YR2/2 brown black fine sandy loam, no gravel. Weak, fine and very fine granular. Soft , friable, non-plastic. Few concretions.
6-14 cm ABt	7.5YR3/2 dark brown fine sandy clay loam, no gravel. Weak, fine and medium granular. Slightly hard, firm , slightly plastic and slightly sticky. Concretions common.
14-29 cm B_1tc	10YR4/3 dull yellow brown fine sandy clay, no gravel. Moderately strong, fine and medium blocky. Dry, firm and plastic. Concretions common.
29-41 cm B_2tc	10YR1/1 brown gray, no gravel. Moderately strong, fine and medium blocky. Hard, firm, plastic and sticky. Concretions abundant.
41-70 cm B_3xc	Massive Concretions dominant.

STF3: Fallow#4 Sort term fallow Very concretionary.

STF3- A1

0-7 cm Ac	7.5 YR 2/2 brown black fine sandy loam with gravel. Weak, fine and very fine granular, soft, friable , non plastic and non sticky. Abundant concretions.
7-15 cm ABc	7.5YR 2/2 brown black loamy fine sand with gravel. Weak, moderately fine granular, soft, very friable , non plastic and non-sticky. Abundant concretions.
15-34 cm B_1tc	7.5YR4/4 sandy clay loam with orange mottles (7.5YR6/8) with abundant gravel. Moderately strong medium coarse blocky with very fine and fine roots, pores and channels. Concretions dominant.
34-44 cm B_2xc	Massive. Concretions dominant.

STF3- B1

0-7 cm Ac	10YR2/2 brown black sandy clay loam with gravel. Weak, fine and very fine granular, soft, very friable , non plastic and non-sticky . Many concretions.
7-15cm ABc	10YR3/3 dark brown loamy fine sand with gravel. Weak to moderately strong, coarse single grain. Loose, friable, non plastic and non sticky. Concretions abundant.
15-28 cm B_1tc	10YR4/4 brown sandy clay loam with orange mottles (7.5YR7/6) and abundant gravel. Weak to moderately strong fine to medium sub-angular blocky, hard, firm, slightly plastic and slightly sticky. Abundant concretions.
28-45 cm B_2ct	10YR5/3 sandy clay no gravel. Moderately strong medium and coarse blocky. Hard, very firm, plastic and sticky. Concretions dominant.
45-71 cm B_3x	Massive. Concretions dominant.

STF3 C1

0-7 cm A1	10YR2/1 black fine sandy loam with gravel. Weak, fine and very fine granular. Soft, friable, non plastic and non sticky. Concretions common.
7-19 cm ABtc	10YR2/2 brown black sandy clay loam with gravel. Weak to moderately strong, fine and medium blocky. Soft slightly hard to firm, lightly plastic and slightly sticky. Concretions abundant.
19-38 cm	10YR3/4 bark brown sandy clay with gravel. Moderately strong, fine and medium blocky.

B_1tc	slightly hard, firm, plastic and sticky. Concretions abundant.
38-56 cm B_2tc	10YR5/4 dull yellow brown sandy clay with yellowish orange mottles and gravel. Moderately strong, fine and medium blocky, hard, very firm, plastic and sticky. Concretions dominant.
56-78 cm B_3x	Massive. Concretions dominant.

STF3- A2

0-5 Ac	10YR3/2 brown black fine sandy loam with gravel. Weak, fine and medium granular. Soft, very friable, non-plastic and non sticky. Concretions common.
5-14 cm ABc	10YR4/2 gray yellow brown fine sandy clay loam with abundant gravel. Weak to moderately strong, fine and medium sub-angular blocky. Slightly hard, friable to firm , slightly plastic and slightly sticky. Concretion common.
14-28 cm B_1tc	5YR3/3 dark red brown sandy clay with gravel. Moderately strong, very fine and fine blocky. Hard, firm, plastic and sticky. Concretions abundant
28-50 cm B_2xc	Massive. Concretions dominant.

STF#4 B2

0-6 cm Ap	10YR2/2 brown black sandy loam with gravel. Weak, fine to very fine granular. Soft , friable and non plastic. Concretions common.
6-16 cm ABtc	10YR3/3 dark brown sandy clay loam with gravel. Weak to moderately strong, fine and medium granular. Slightly hard, firm and slightly plastic. Concretions many.
16-41 cm B_1tc	2.5YR3/4 dark red brown sandy clay with gravel. Moderately strong, fine and medium blocky, hard, very firm, plastic and sticky. Concretions abundant.
41-64 cm B_2x	Massive. Concretions dominant.

STF#4 C2

0-5 cm Apc	10YR3/1 brown black sandy loam no gravel. Weak, fine to very fine granular. Soft, friable, non plastic. Fe and Mn Concretions many.
5-11 cm ABc	10YR3/3 dull brown sandy clay loam with some gravel. Weak to moderately strong, fine and medium blocky. Soft to slightly hard, friable to firm , slightly plastic, slightly sticky. Concretions abundant.
11-24 cm B_1tc	2.5YR dull red brown clay loam with gravel. Moderately strong, fine and medium blocky, hard, firm and plastic. Concretions abundant.
24-70 cm B_2x	Massive. Concretions dominant.

STF#4 A3

0-6 cm Apc	10YR sandy loam with gravel. Very weak, fine to medium granular. Soft , friable and, non plastic . Concretions abundant.
6-13 cm ABc	11 YR fine sandy loam with gravel. Moderately strong, fine and medium granular. Slightly hard, slightly firm and non-plastic. Concretions abundant.
13-44 cm Bx	Massive. Concretions dominant.

STF#4 B3

0-5 cm Ap	10YR fine sandy loam no gravel. Strong, fine granular. Soft, friable and non-plastic. Concretions common.
5-13 cm ABc	10YR sandy loam no gravel. Strong, fine and sub-angular blocky . Slightly hard , firm, slightly plastic. Concretions many.
13-40 cm B_1tc	10YR sandy clay, no gravel. Strong, fine to very fine blocky.. Hard , firm to very firm and plastic and sticky. Concretions abundant.
40-65 cm B_2tc	10YR clay, no gravel. Strong, very fine blocky. Very hard, very firm, plastic and sticky. Concretions dominant.

STF#4 C3

0-6 cm Ap	7.5YR2/2 brown black fine sandy loam, no gravel. Weak, fine and very fine granular. Soft , friable, non-plastic. Few concretions.
6-14 cm ABtc	7.5YR3/2 dark brown fine sandy clay loam, no gravel. Weak, fine and medium granular. Slightly hard, firm , slightly plastic and slightly sticky. Abundant concretions.
14-29 cm B_1tc	10YR4/3 dull yellow brown fine sandy clay, no gravel. Moderately strong, fine and medium blocky. Dry, firm and plastic. Concretions abundant.
29-41 cm B_2tc	10YR1/1 brown gray, no gravel. Moderately strong, fine and medium blocky. Hard, firm, plastic and sticky. Concretions dominant.
41-70 cm B_3x	Massive. Concretions dominant.

ABF4: Active bush farm#4

Very sandy. No concretions. Close to the bush rice farm.

ABF#4 A1

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A_2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-30 cm B	5YR4/4 Yellowish brown coarse sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Very few concretions

ABF#4 B1

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A_2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-34 cm B	5YR4/4 Yellowish brown coarse sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Very few concretions

ABF#4 C1

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A_2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-30 cm B	5YR4/4 Yellow grey coarse sandy loam with orange and brown mottles (7.5YR6/8) few gravel. Granular, non plastic and non sticky. Very few concretions

ABF#4 A2

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A_2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-30 cm B	5YR4/4 Yellow grey coarse sandy loam with orange and brown mottles (7.5YR6/8) few gravel. Granular, non plastic and non sticky. Very few concretions

ABF#4 B2

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A_2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-30 cm B	5YR4/4 Yellow grey coarse sandy loam with orange and brown mottles (7.5YR6/8) few gravel. Granular, non plastic and non sticky. Very few concretions

ABF#4 C2

0-10 cm Ap	5 YR 5/4 Brown black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-30 cm B	5YR4/4 Yellow grey coarse sandy clay loam with orange and brown mottles (7.5YR6/8) few gravel. Moderately strong subangular, plastic and sticky. Very few concretions

ABF#4 A3

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-30 cm B	5YR4/4 Yellowish brown coarse sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Very few concretions

ABF#4 B3

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-34 cm B_1	5YR4/4 Yellowish brown coarse sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Very few concretions

ABF#4 C3

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Very few concretions
20-34 cm B_1	5YR4/4 Yellowish brown coarse sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse single grain. Very few concretions

Active bush farm#5 Valley soil with concretions

ABF#5 A1

0-10 cm Ap	5 YR 5/4 Black sandy loam. Weak, single grain, non plastic and non sticky. Many concretions.
10-20 cm A_2	5YR 4/3 Black sandy loam. Weak, non plastic and non-sticky. Many concretions
20-30 cm B	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Many concretions

ABF#5 B1

0-10 cm Ap	5 YR 5/4 Black loamy sand. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A_2	5YR 4/3 Brown clay loam. Slightly plastic and sticky. Whitish stains, saprolite in nature. Concretions common.
20-30 cm B	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Concretions common

ABF#5 C1

0-10 cm Ap	5 YR 5/4 Black sandy loam. Weak, single grain, non plastic and non sticky. Concretions common..
10-20 cm A_{2c}	5YR 4/3 Black sandy loam. Weak, non plastic and non-sticky. Many concretions
20-30 cm B_{1c}	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Many concretions

ABF#5 A2

0-10 cm Apc	5 YR 5/4 Black sandy loam. Weak, single grain, non plastic and non sticky. Concretions many.
10-20 cm A_{2c}	5YR 4/3 Black sandy loam. Weak, non plastic and non-sticky. Abundant concretions
20-30 cm Bc	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Concretions abundant.

ABF#5 B2

0-10 cm Ap	5 YR 5/4 Black loamy sand. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A_2	5YR 4/3 Brown clay loam. Slightly plastic and sticky. Whitish stains, saprolite in nature. Concretions common.
20-30 cm B	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Concretions common.

ABF#5 C2

0-10 cm Apc	5 YR 5/4 Black loamy sand. Weak, single grain, non plastic and non sticky. Concretions many.
10-20 cm A2c	5YR 4/3 Brown clay loam. Slightly plastic and sticky. Whitish stains, saprolite in nature. .Many concretions
20-30 cm Bc	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Many concretions.

ABF#5 A3

0-10 cm Ap	5 YR 5/4 Black loamy sand. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Brown clay loam. Slightly plastic and sticky. Whitish stains, saprolite in nature. Concretions common.
20-30 cm	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately

B	strong medium coarse blocky. Concretions common.

ABF#5 B3

0-10 cm Ap	5 YR 5/4 Black loamy sand. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Brown clay loam. Slightly plastic and sticky. Whitish stains, saprolite in nature. Few concretions
20-30 cm B	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Few concretions

ABF#5 C3

0-10 cm Ap	5 YR 5/4 Black loamy sand. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Brown clay loam. Slightly plastic and sticky. Whitish stains, saprolite in nature. Few concretions
20-30 cm B	5YR4/4 Grey brown sandy clay loam with orange mottles (7.5YR6/8) few gravel. Moderately strong medium coarse blocky. Few concretions

Active bush farm#6

Valley soil, no concretions. Very productive, being farmed for generations.

ABF#6 A1

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Very few concretions
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Very few concretions

ABF#6 B1

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Very few concretions

C11C

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Concretions common
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Concretions common.
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Concretions common.

ABF#6 A2

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Very few concretions.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Very few concretions
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Very few concretions

ABF#6 B2

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Concretions common.
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Concretions common.

ABF#6 C2

0-10 cm Ap	5 YR 5/4 Grey brown sandy loam. Weak, single grain, non plastic and non sticky. Few concretions.
10-30 cm A2	5YR 4/3 Grey brown silty clay loam. Slightly sticky and plastic. Saprolite in nature. Few concretions

ABF#6 A3

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Concretions many.
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Concretions many.

ABF#6 B3

0-10 cm Ap	5 YR 5/4 Brown black sandy loam. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Few concretions
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Few concretions

ABF#6 C3

0-10 cm Ap	5 YR 5/4 Brown black washed sand. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2	5YR 4/3 Black clay loam. Slightly firm, plastic non-sticky. Concretions common.
20-30 cm B	5YR4/4 Black clay loam with white stains, few gravel. Moderately strong medium coarse blocky. Concretions common.

ABF7:

Active bush farm#7 Close to the valley, concretionary and stony, with a stone line. Saprolite close to surface

ABF#7 A1

0-10 cm Ap	5 YR 5/4 Grey black loamy coarse sand. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2c	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Many concretions and sand stones
20-30 cm Bc	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Abundant concretions.

ABF#7 B1

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Concretions common. Pieces of sand stone in powdered saprolite.
20-30 cm B	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Concretions common. Pieces of sand stone in powdered saprolite.

ABF#7 C1

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2c	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Concretions common. Pieces of sand stone in powdered saprolite.
20-30 cm Bc	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Many concretions and pieces of clay and sand stone in powdered saprolite.

ABF#7 A2

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2c	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Many concretions and pieces of clay and sand stone in powdered saprolite.
20-30 cm Bc	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Abundant concretions and pieces of clay and sand stone in powdered saprolite.

ABF#7 B2

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Concretions common.

10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Concretions common. Pieces of sand stone in powdered saprolite.
20-30 cm B	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Concretions common. Pieces of sand stone in powdered saprolite.

ABF#7 C2

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Many concretions and pieces of clay and sand stone in powdered saprolite.
20-30 cm B	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Abundant concretions and pieces of clay and sand stone in powdered saprolite.

ABF#7 A3

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Few concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Few concretions and Pieces of clay and sand stone in powdered saprolite.
20-30 cm Bc	5YR4/4 Yellowish brown coarse sandy clay loam. Moderately strong medium coarse blocky. Many concretions and pieces of clay and sand stone in powdered saprolite.

ABF#7 B3

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Many concretions.
10-20 cm A2	5YR 4/3 Grey brown coarse sandy loam. Weak, non plastic and non-sticky. Abundant concretions and pieces of clay and sand stone in powdered saprolite.
20-30 cm Bc	5YR4/4 Yellowish brown coarse sandy clay. Moderately strong medium coarse blocky. Abundant concretions and pieces of clay and sand stone in powdered saprolite.

ABF#7 C3

0-10 cm Ap	5 YR 5/4 Brown Fine sandy loam. Weak, single grain, non plastic and non sticky. Concretions common.
10-20 cm A2	5YR 4/3 Grey brown washed sandy loam. Weak, non plastic and non-sticky. Abundant concretions and quartz gravels and stones
20-30 cm Bc	5YR4/4 Yellowish brown coarse sandy clay. Moderately strong medium coarse blocky. Abundant concretions and pieces of clay and sand stone in powdered saprolite.

Site: ABF7 (pit)

Depth	Description
0-10cm Ap	Fine sandy loam, wk fine granular loose fine roots common. Non plastic and non-sticky. Brown black.
10-18cm A_2	Gritty sandy loam. Wk fine granular, single grains. Few fine roots. Non plastic and non-sticky.
18-32cm B_1	Gritty sand, single grain, wk loose non plastic non-sticky Few fine rounded Fe-conc. Clear boundary. Few roots
32-48cm B_{2c}	Coarse sand, Few roots. Fine and moderately coarse gravel forming a stone line.
48-61cm Bt	Clayey, olive grey with grey and yellow mottles and MnO_2 crystals. Sticky and plastic
61-100cm BC	Clay and weathered rock. Olive grey and very hard, blocky

CRF

In the valley close to the compound farms no concretions with seasonal water logging conditions.
Use for rice farming.

CRF A1

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular

B_t	blocky, sticky and plastic. Very few concretions.

CRF B1

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CRF C1

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CFR A2

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CRF B2

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CRF C2

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CRF A3

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CRF B3

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm A2	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

CRF C3

0-10 cm Ap	5 YR 5/4 Grey black clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic. Very few concretions.
10-20 cm	5YR 4/3 Grey brown clay loam. Firm and medium sub-angular blocky, slightly sticky and plastic.

A2	Very few concretions.
20-30 cm B_t	5YR4/4 Yellowish clay loam with orange mottles (7.5YR6/8). Firm and medium sub-angular blocky, sticky and plastic. Very few concretions.

Appendix B

Plant species encountered at the Uncultivated site

Life form	Number of individual plants	Frequency	Density (# of pts/m²)	Relative frequency (%)	Relative density (%)
		Woody trees/shrubs			
Acacia goumensis	8	11	0.44	11	22
Pterocarpus eri.	7	17	0.39	17	20
Butyrospernum para.	7	17	0.39	17	20
Sterospernum tem.	4	11	0.22	11	11
Combretum glu	2	5	0.11	5	6
Acacia alb.	2	11	0.11	11	6
Terminalia avi.	2	11	0.11	11	6
Terminalia mollis	1	5	0.05	5	3
Combretum gas	1	5	0.05	5	3
Anona senegalenses.	1	5	0.05	5	3
		Herbs			
Hibiscus Vitilitus	34	33	1.89	18	30
Borreria scarba	32	22	1.78	12	28
Desmodium sp.	9	11	0.5	6	8
Aspillia sp.	8	17	0.44	10	7
Tephrosia elegance	6	11	0.44	6	5
Thisium viridi	4	5	0.22	3	3
Synedrella nodiflora	3	33	0.17	6	3
Anchiosus sp.	3	11	0.17	6	3
Angiossis leicarpus	2	5	0.11	3	2
Indigofera puchra	2	11	0.11	6	2
Philantha sab.	2	5	0.11	3	2
Stylosanthus hypo.	1	5	0.05	3	1
Cyphostana cyn.	1	5	0.05	3	1
Dioscorea lecardii	1	11	0.05	3	1
Cassia munesiodis	1	5	0.05	3	1
Cuculigo pilosa	1	5	0.05	3	1
Tridax procubens	1	5	0.05	3	1
Vigna pubesens	1	5	0.05	3	1
		Grasses			
Heteropogon contortus	49	28	2.72	21	30
Angropogon gayanus	38	28	2.11	21	23
Rottboelia exal.	22	17	1.22	13	13
Seteria	19	22	1.05	16	12
Brachiara jubata	15	17	0.83	13	9
Andropogon schirensis	10	5	0.55	4	6
Hyperrhinia rufa	8	5	0.44	4	5
Cyperus sp.	4	11	0.22	8	9

50-year fallow

Life form	Number of individual plants	Frequency	Density (# of pts/m^2)	Relative frequency (%)	Relative density (%)
		Woody trees/shrubs			
Pterocarpus eri.	8	15	0.4	17	26
Acacia goumensis	6	15	0.3	17	19
Anona senegalenses.	5	5	0.25	5	16
Butyrospernum para.	3	15	0.15	17	10
Terminalia mollis	3	10	0.15	11	10
Stryhnos spinosa	3	15	0.15	17	10
Sterospernum tem.	1	5	0.05	5	3
Mayterus senegalense	1	5	0.05	5	3
Entado abysin	1	5	0.05	5	3
		Herbs			
Indigofera puchra	10	30	0.5	40	48
Commelina erectra	6	25	0.3	33	28
Euphobia sp.	2	5	0.1	7	9
Cochlocpernum sp	2	10	0.1	7	5
Tephrosia elegance	1	5	0.05	7	5
		Grasses			
Heteropogon contortus	49	28	2.72	21	30
Angropogon gayanus	38	28	2.11	21	23
Rottboelia exal.	22	17	1.22	13	13
Seteria	19	22	1.05	16	12
Brachiara jubata	15	17	0.83	13	9
Andropogon schirensis	10	5	0.55	4	6
Hyperrhinia rufa	8	5	0.44	4	5
Cyperus sp.	4	11	0.22	8	9

LTF2

Life form	Number of individual plants	Frequency	Density (# of pts/m²)	Relative frequency (%)	Relative density (%)
		Woody trees/shrubs			
Combretum gasalense	3	20	0.3	30	38
Acacia goumensis	1	10	0.1	14	13
Anona senegalenses.	1	10	0.1	14	13
Butyrospernum para.	1	10	0.1	14	13
Terminalia avi.	1	10	0.1	14	13
Sterospernum tem.	1	10	0.1	14	13
		Herbs			
Borreria scaba	39	13	3.9	56	59
Tephrosia eleganse	25	8	2.5	35	38
Euphobia sp.	1	1	1	4	15
Cassia minosa	1	1	1	4	15
		Grasses			
Andropogan shirenses	37	60	3.7	40	0.46
Eragrostis curalin	24	30	2.4	20	0.30
Angropogon gayanus	11	50	1.1	33	0.14
Rottboelia exal.	8	10	0.8	7	0.10

STF1

Life form	Number of individual plants	Frequency	Density (# of pts/m²)	Relative frequency (%)	Relative density (%)
		Woody trees/shrubs			
Combretum gasalense	1	10	0.1	25	25
Acacia goumensis	1	10	0.1	25	25
Anona senegalenses.	1	10	0.1	25	25
Stylochnos spinosa	1	10	0.1	25	25
Terminalia avi.	1	10	0.1	25	25
		Herbs			
Tephrosia eleganse	32	40	3.2	31	57
Tridax procumbense	21	60	2.1	46	37
Indigofera pulcha	2	20	0.2	15	4
Borreria scaba	1	10	0.1	8	2
		Grasses			
Andropogan shirenses	37	60	3.7	40	0.46
Eragrostis curalin	24	30	2.4	20	0.30
Angropogon gayanus	11	50	1.1	33	0.14
Rottboelia exal.	8	10	0.8	7	0.10

STF2

Life form	Number of individual plants	Frequency	Density (# of pts/m^2)	Relative frequency (%)	Relative density (%)
		Woody trees/shrubs			
		Herbs			
Stylochicum hypogea	10	60	2.0	20	29
Cloeme viscosa	7	40	1.4	13	21
Cassia minosiodes	5	40	1.0	13	15
Borreria scaba	4	40	0.8	7	12
Hibiscus sp.	3	60	0.2	7	9
Phillanthus sabratus	1	20	0.2	7	3
Biophylum petroz.	1	20	0.2	7	3
Cucumis mello	1	20	0.2	7	3
Cuculigo pilosa	1	20	0.2	7	3
Vigna pubugin	1	20	0.2	7	3
		Grasses			
Paspallum sp	51	100	10.2	56	82
Brachiria stigmatus	6	40	1.2	22	10
Rottboelia exal.	4	20	0.8	11	6
Andropogan gayanus	1	20	0.2	11	2

STF3

Life form	Number of individual plants	Frequency	Density (# of pts/m^2)	Relative frequency (%)	Relative density (%)
		Woody trees/shrubs			
		Herbs			
Tephrosia elegance	23	60	4.6	43	72
Tridax procumbense	7	60	0.4	43	22
Cassia mimossis	3	20	0.4	13	6
		Grasses			
Brachiria stigmatus	32	100	6.4	36	39
Digitaria	30	100	6.0	36	37
Dactylotum aegypton	19	60	3.8	21	23
Eragrostis cum.	1	20	0.2	7	1

APPENDIX C : Socio-economic Survey Questionnaire

Demographic and Personal information

1. Sex: Male__________Female______
2. Place of Birth________________________________
3. Family's place of origin (region)___________________
4. Local Government area ____________Village________Tribal group_______
5. Age (Please tick)
______a) 25 or less
______b) 26-35
______c) 36-45
______d) 46-55
______e) 56-65
______f) 66 or more
6) Level of formal education (Please tick)
______a) illiterate
______b) primary school
______c) secondary school
______d) post-secondary school
______e) others (specify)__________________________
7. Marital status (Please tick)
______a) married
______b) never married
______c) divorced
______d) widowed
IF male, number of wife________________________
IF female, rank within marriage (if in polygamous marriage)__________
8. Number of children alive________________________________
9. How many people live altogether in your household____________
10. Persons who are away temporarily down south working _________
11. Is Farming your major occupation? (Please tick)
_______a) Yes
_______b) No
12. How many years have you been farming? ___________________
13. What do you consider your main agricultural activity? (Please tick)
_______a) Crop production_______ b) Livestock production
14. Has this always been your major activity (Please tick)
______a) Yes______ b) No
IF No, explain____
15. What crops do you plant ? (Please list in order of acreage)__________________
____
16. Which kind and number of animals belong to the household?
__________a) cow _______c) goat d) poultry___________
__________b) sheep _______d) pig f) bullock___________
17. Do you have any off-farm employment? Yes_____No_____

Availability of land

1. How do you get land for farming? (Please tick)
__________a) community/ family inheritance
__________b) government
__________c) rent

__________d) others (specify)______________________________________

2. Is it easy for every one in the community to acquire land for farming? (Please tick)

_________a) Yes

_________b) No

3. Do you think the current system of land tenure is fair to all ? (Please tick)

_________a) Yes

_________b) No

4. Does your farm consist of several small plots or one big one? (Specify)__________

IF there are several small ones;

a) how many are they______________________________________

b) how far apart are they______________________________________

c) why are they separated______________________________________

5. What is the size of each of your farms (acres or local measure)_______________

6. Does it belong to :

_______a) you

_______b) family/community

_______c) govt.

_______d) others (specify)______________________________________

7. Is it easy to acquire more land for farming? (Please tick)

_______a) Yes

_______b) No

IF Yes, what would be the source of this extra land?_________________________

what would be the distance from the current lands_____________________

what type of land would it be? (Please tick)

________a) fallow land

________b) native land

8. Is it easy for non-natives to get land for farming? (Please tick)

_______a) Yes

_______b) No

Land use and Land degradation

1. How long have you been farming :

a) your current compound farm land________________

b) your current bush farm land____________________

2. In these years have you noticed any change in the condition of your

a) compound farm land (Please tick)

_________Yes

_________No

b) bush farm land (Please tick)

_________Yes

_________No

3. What is the condition of your:

a) compound farm land today compared to when you started farming it. (tick)

Is it becoming : BAD/WORSE_____BETTER_____NO-CHANGE_____

4. What is the condition of your:

a) bush farm land today compared to when you started farming it. (Please tick)

Is it becoming : BAD/WORSE_____BETTER_____NO-CHANGE_____

5. What can you say about the quality of your neighbour's farm land? _____________

____

6. What is the general condition of land belonging to the village? (Please tick)

a) compound farm land: Is it becoming BAD___BETTER___NO-CHANGE___

b) bush farm land: Is it becoming BAD___BETTER___NO-CHANGE___

7. Can you farm more land when necessary?(Please tick)

__________a) Yes
__________b) No
IF Yes:
    a) how can you get more land?______________________________
    b) would it be near or far? ______________________________
    c) would it be 'fallow' land or 'native' land______________________________
8. Is it easy for strangers to have access to farm land? (Please tick)
______a) Yes
______b) No
IF Yes, how many strangers had acquired land during the last farming season? ________
9. What would you say about the availability of farm land today as compared to 30 years ago? (Please tick).
_____a) more readily available
_____b) less readily available
_____c) same as before
10. Has the length of land cultivation before fallow increased over the last 30 years? (tick)
_____a) Yes
_____b) No
IF Yes, why______________________________
11. Is it easy to find 'fallowed land for cultivation in your community? (Please tick)
_____a) Yes
_____b) No
12. How can you tell :
    a) a 'good' virgin land from a 'bad' virgin land?____________________
____
    b) a 'good' active farm land from a 'bad' active farm land? ______________
____
    c) a 'good' fallow land from a 'bad' fallow land____________________
____
13. Do you have some abandoned farm lands in your community? (Please tick)
______a) Yes
______b) No
IF Yes, why are these farm lands abandoned?______________________________
14. How do you tell the difference between and 'abandoned' land and a 'fallow' land? ____
____
____
15. On your own farm land, have you ever:
    a) made contour bounds? YES_____NO______
    b) stone lines? YES_____NO______
    c) planted trees YES_____NO______
16. Have you ever, done any of these on community land? YES___NO___
IF Yes, Please specify the type of activity______________________________
____
17. Where is your household fuel collected? (Please tick)
______a) own farm land
______b) community land
______c) both
18. Is firewood collection becoming : EASIER__DIFFICULT__NO-CHANGE__
19. Do you or any of your household members make charcoal? YES_____NO_____
IF Yes, how many times do they make charcoal in a year?____________________
    how many bags do they make in a year? ____________________
20. Do you think charcoal making had increased in your community over the last 30 years?.
YES___NO_____
IF Yes, what is the reason for this increase?______________________________

THANK YOU FOR YOUR TIME

Labour

1. How many of your household members work on the household farm?
   a) full time (men_____women______children_______)
   b) part-time (men____women_______children______)
2. Does the farm household hire any cash paid labour for:
   a) land preparation Yes_____No____
   b) planting Yes_____No____
   c) weeding Yes_____No____
   d) harvesting Yes_____No____
3. Do you engage communal labour for :
   a) land preparation Yes_____No____
   b) planting Yes_____No____
   c) weeding Yes_____No____
   d) harvesting Yes_____No____
4. What is the busiest month of the year for the farm household? ____________________
5. Is labour readily available at this time? Yes______No____

Agricultural services

1. Is there a Ministry of Agriculture office and or an Agricultural Development Project situated in or near your community? Yes______No______
   IF yes, have you ever benefited from their services? Yes_____No_____
   State how____
2. Do you use animal manure on:
   a) compound farm Yes______No_______
   If No, why?____
   b) bush farm Yes______No_______
   If No, why?____
3. Do you use chemical fertilizers on
   a) compound farm Yes______No________
   If No, why?____
   b) bush farm Yes______No_______
   If No, why?____
4. Do you use improved seed ? Yes______No_______
   If No, what is the source of your seed_____________________________
5. Do you use pesticide on any crop? Yes______No________
   If Yes, which crops?______________________________________
6. Do you use : (Please tick)
______a) tractor
______b) bullock
______c) both
______d) none
   If you use tractor, is it:
   _____a) your own
   _____b) rented
   If you use bullock
   _____a) your own
   _____b) rented
7. Do you have access to credit? Yes_______No_______
   If Yes, in what form? (e.g. cash, input etc.) Specify_________________________
8. How readily available are farming inputs to you? (Please tick)

	<u>readily on time</u>	<u>sometimes</u>	<u>rarely or not</u>	
a) fertilizer	[1]		[2]	[3]
b) chemical spray	[1]	[2]	[3]	

c) seeds [1] [2] [3]
d) tractor [1] [2] [3]
e) others (Specify)____
9. If rarely or not available, do you know why?____________________________

____

____

10. From what source do you get your farm information (e.g. radio, TV, Extension agents, other farmers, [specify])________________________________
11. Are you a member of any of the following? (Please tick)
________a) farmers' cooperative
________b) farmers' association
________c) others (specify)____
12. How useful has your membership in any one or more of these groups been to you?
____a) very useful
____b) useful
____c) sometimes useful
____d) rarely useful
13. If useful, in what way?____

____

Marketing and financial resources

1. Do you:
   a) sell all your crops? Yes_______No_______
   b) consume all in the house Yes_______No_______
   c) sell part and consume part Yes_______No_______
2. If you do market part of your crop, what proportion do you market?______________
3. What major problems do you face in marketing your crops? (Please specify)_________

____

____

____

____

4. What do you think is needed to improve your present marketing practices? (specify)___

____

____

____

5. How many members of your household contribute to the household income (money, produce etc.)

____

6. What are the main sources of income for the household? (Rank 1= highest, 2= second highest etc.)
_______a) agriculture
_______b) employment
_______c) charcoal making
_______d) trading
_______e) handicraft
_______f) employment outside the region
_______g) others (specify)____
7. What are the main cash expenditure during the year (e.g. food, school fees, clothing, social obligations, farm inputs etc.). Please list and indicate when they occur

<u>**Expenditure**</u> <u>**Time of occurrence**</u>

____

____

____

____

____

THANK YOU FOR YOUR TIME

Problem ranking

1. Have any major changes taken place over the last 30 years related to:

a) crops you grow? Yes_____No_____

IF yes, please describe____

____

b) land tenure? Yes______No_____

IF yes, please describe____

____

c) prices of inputs:

i) fertilizer Yes______No_____

IF yes, please describe____

ii) seed Yes______No_____

IF yes, please describe____

iii) agrochemical Yes______No_____

IF yes, please describe____

d) pest:

i) occurrence Yes_____No______

IF yes, please describe____

ii) type Yes_____No_______

IF yes, please describe____

e) occurrence of bush fires Yes_____No_______

IF yes, please describe____

f) Others (specify and describe) ____

____

____

____

2. Rank the following problems related to your agricultural activities (Rank by numbering 1, 2, 3, etc. with 1 = the most important).

______a) declining soil fertility

______b) lack of adequate land for farming

______c) lack of relevant information to sustain agricultural production

______d) lack of agricultural inputs

_____tools (please rank)

_____seed

_____fertilizer

_____agrochemicals

_____marketing facilities

_____others (specify)____

3. What is the most important cause of the problems you have just mentioned?. How do they affect your production decision and how do you deal with them?

1st Problem:(specify)____

Cause____

Effect on production decisions____

Strategy/solutions____

____

2nd Problem: (specify)____

Cause____

Effect on production decisions____

Strategy/solutions____

____

3rd Problem: (specify)____

Cause____
Effect on production decisions________________________________
Strategy/solutions____

____

4th Problem: (specify)____________________________________
Cause____
Effect on production decisions________________________________
Strategy/solutions____

____

Other Problems: (specify)__________________________________
Cause____
Effect on production decisions________________________________
Strategy/solutions____

____

THANK YOU FOR YOUR TIME